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PRELIMINARY DESIGN OF A FAMILY OF THREE CLOSE AIR SUPPORT AIRCRAFT

PREPARED FOR: USRA NASA GRANT #NGT-8001

PREPARED BY:

BRIAN COX
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UNIVERSITY OF KANSAS
AE 622
17 MAY 1989

TEAM LEADER: JEFF TUSCHHOFF

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Abstract

A family of three Close Air Support aircraft is presented. These aircraft are designed with commonality as the main design objective to reduce the life cycle cost. The aircraft are low wing, twin-boom, pusher turbo-prop configurations. The amount of information displayed to the pilot was reduced to a minimum to greatly simplify the cockpit. The aircraft met the mission specifications and the performance and cost characteristics compared well with other CAS aircraft. The concept of a family of CAS aircraft seems viable after preliminary design.

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LIST OF SYMBOLS

Symbol	Definition	Units
A	Aspect ratio	
a	Alpha; angle of attack	[deg]
a_{o_l}	Airfoil zero lift angle of attack	[deg]
b	Span	[in,ft]
$\bar{c}$	Mean geometric chord	[in,ft]
C_D	Drag coefficient	
C_{D_a}	Variation of drag coefficient with angle of attack	[/rad]
C_{D_u}	Variation of drag coefficient with speed (i.e. speed damping)	
C_L	Lift coefficient	
c_{l_a}	Airfoil lift curve slope	[/rad]
C_{L_a}	Airplane lift curve slope	[/rad]
$C_{L_{\dot{a}}}$	Variation of lift coefficient with rate of change of angle of attack	[/rad]
C_{l_B}	Variation of rolling moment coefficient with sideslip angle	[/rad]
$C_{l_{d_A}}$	Variation of rolling moment coefficient with aileron angle (i.e. lateral control power)	[/rad]
$C_{l_{d_R}}$	Variation of rolling moment coefficient with rudder angle	[/rad]
C_{L_o}	Lift coefficient for zero angle of attack, zero elevator angle and zero stabilizer angle	
$C_{L_{d_e}}$	Variation of lift ceofficient with elevator angle	[/rad]
C_{l_p}	Variation of rolling moment coefficient with roll rate	[/rad]

Symbol	Definition	Units
C_{L_q}	Variation of lift coefficient with pitch rate	[/rad]
C_{l_r}	Variation of rolling moment coefficient with yaw rate	[/rad]
C_{L_u}	Variation of lift coefficient with speed	
C_{n_B}	Variation of yawing moment coefficient with sideslip angle	[/rad]
$C_{n_{d_A}}$	Variation of yawing moment coefficient with aileron angle	[/rad]
$C_{n_{d_R}}$	Variation of yawing moment coefficient with rudder angle	[/rad]
C_{n_p}	Variation of yawing moment coefficient with roll rate	[/rad]
C_{m_a}	Variation of pitching moment coefficient with angle of attack (i.e. static longitudinal stability)	[/rad]
$C_{m_{\dot{a}}}$	Variation of pitching moment coefficient with rate of change of angle of attack	[/rad]
$C_{m_{d_e}}$	Variation of pitching moment coefficient with elevator angle (i.e. longitudinal control power)	[/rad]
C_{m_o}	Pitching moment coefficient for zero angle of attack, zero elevator angle and zero stabilizer angle	
C_{m_q}	Variation of pitching moment coefficient with pitch rate	[/rad]
C_{m_u}	Variation of pitching moment coefficient with speed	
C_{n_r}	Variation of yawing moment coefficient with yaw rate	[/rad]
C_{y_B}	Variation of side force coefficient with sideslip angle	[/rad]
$C_{y_{d_R}}$	Variation of side force coefficient with rudder angle	[/rad]

Symbol	Definition	Units
C_{y_p}	Variation of sideforce coefficient with roll rate	[/rad]
C_{y_r}	Variation of side-force coefficient with yaw rate	[/rad]
de/da	Downwash angle per angle of attack	
d_a	Aileron deflection angle	[deg]
$d_{f_{ave}}$	Fuselage average diameter	[ft]
i_h	Horizontal tail incidence angle	[deg]
l_f	Fuselage length	[ft]
l_v	Vertical tail aerodynamic center horizontal location behind the airplane center of gravity location	[ft]
M	Mach number	
n	Load factor	
S	Area	[sqf]
S_{BS}	Body side area	[sqf]
$\bar{V}_h$	Horizontal tail volume coefficient	
w_n	Natural frequency	
W	Weight	[lbs]
$\bar{x}_{ac}$	Aerodynamic center location / mean geometric chord	
$\bar{x}_{cg}$	Center of gravity location / mean geometric chord	
$\bar{x}_{ref}$	Reference point location / mean geometric chord	
x_w	Distance of center of gravity to wing aerodynamic center (+) if c.g. is forward of a.c.	[ft]
zeta	Damping ratio	
z_f	Vertical height of fuselage at wing root chord	[ft]

Symbol	Definition	Units
z_v	Vertical tail aerodynamic center vertical location above (+) or below (-) the airplane center of gravity location	[ft]
z_w	Vertical distance from the wing root chord to the fuselage average diameter center location	[ft]

Subscripts:

aft	aft
fwd	forward
h	Horizontal tail
v	Vertical tail
c/2	Half chord
c/4	Quarter chord
eff	Effective
TO	Take-off
OE	Operating empty
E	Empty
SP	Short period
P	Phugoid

Acronyms:

AC	Aerodynamic center
API	Armor piercing incendiary
BL	Buttock line
CAS	Close Air Support
CG	Center of gravity
CGR	Climb gradient
CRT	Cathode ray tube
ECM	Electronic counter measure
FLIR	Forward looking infrared radar
FS	Fuselage station
GPS	Global positioning system
HDD	Heads down display
HEI	High explosive incendiary
HUD	Heads up display
IFF	Identify friend or foe
MG	Main gear
MGC	Mean geometric chord
NG	Nose gear
NVG	Night vision goggles
RAT	Ram Air Turbine
SL	Sea level
SLS	Sea level standard
TA	Terrain avoidance
TF	Terrain follow
TRNS	Terrain Reference Navigation System
UHF	Ultra high frequency
VHF	Very high frequency
WL	Water line

1. INTRODUCTION

In the event of a Warsaw Pact - NATO confrontation, the main attack by the Warsaw Pact forces will most likely focus on the Fulda Gap in West Germany. This predicted attack will be spearheaded by the Soviet ground forces stationed in East Germany. The attack force could consist of as many as 90+ divisions with each division containing roughly 300 main battle tanks and 1,000 other tracked vehicles. To prevent such an assault from succeeding, a means of destroying Soviet battle tanks must be introduced.

There are three weapons available to perform the anti-tank mission: I) tank against another tank, II) a well trained soldier armed with anti-tank weapons, and III) Close Air Support (CAS) aircraft (both helicopters and fixed-wing aircraft).

Through the sponsorship of a NASA/USRA grant, a team of students concluded that a family of three CAS aircraft is needed to help perform the anti-tank missions. The aircraft are:

A) An aircraft to take out advancing armor and highly defended targets (such as fuel or ammunition depots, enemy headquarters, etc.) in all weather conditions.
B) An aircraft with reduced capabilities from the aforementioned aircraft (less range and less payload) but with a lower cost that can attack tanks in fair weather and night/day conditions.
C) A very low cost aircraft that, through shear numbers, halts the advancing tank formations in fair weather conditions.

The three aircraft have been taken through preliminary design. The purpose of this report is to present this work. Reference 1 - 7 are reports leading up to this report. Shelby J. Morris, Jr. of NASA Langley Research Center is the technical adviser for the project. Carol Hopf is the contact at the Universities Space Research Association.

The mission specifications and profiles are presented in Chapter 2 and a brief history of Close Air Support aircraft is presented in Chapter 3. Chapter 4 discusses the configurations. The weight and balance for the aircraft is presented in Chapter 5. Chapter 6 gives the performance characteristics while Chapter 7 presents the stability and control. The structural and system layouts are presented in Chapters 8 and 9. A life cycle cost analysis is shown in Chapter 10. Chapter 11 compares these three aircraft with other CAS aircraft with regard to performance and cost. The conclusions and recommendations are discussed in Chapter 12. The detailed engineering calculations are provided in the appendices.

2. CLOSE AIR SUPPORT AIRCRAFT DEFINITION

The purpose of this chapter is to present the mission specifications and mission profiles for a family of three close air support (CAS) aircraft. Commonality will be incorporated between the three aircraft to a large extent. Typical mission/armament combinations will also be addressed. These aircraft will be utilized by Army ground forces to provide forward close air support.

Several hypothetical battle scenarios have been investigated by the design team (Reference 1). The primary threat appears to be from eastern bloc countries, centered around the Soviet Union. Soviet ground forces rely heavily on tanks, armored fighting vehicles, and artillery. Since the main battle tanks are the centerpiece of a Soviet attacking force, the primary goal of close air support aircraft is to destroy the advancing tanks. Other high priority targets will also be of interest to CAS aircraft.

The three mission specifications and accompanying mission profiles are the subject of this section. The three CAS aircraft consist of:

1) A highly capable advanced close air support aircraft.
2) A modest technology, moderate cost ground attack aircraft.
3) A simple, low cost ground attack aircraft.

The aircraft are named:

The Good - Aircraft 1
The Bad - Aircraft 2
The Ugly - Aircraft 3

2.1 Specifications for an Advanced Close Air Support Aircraft (the Good)

The main goal of the advanced close air support aircraft is to support Army ground forces in day or night, all-weather operations. This aircraft will incorporate a high technology level, and may be seen as a follow-on to the Fairchild A-10. Although assigned primarily to heavy armor engagement, high priority and heavily defended targets will be delegated to this aircraft. The mission specification for the airplane is presented in Table 2.1, with the accompanying mission profile in Figure 2.1.

Table 2.1 - Mission Specification for an Advanced Close Air Support Aircraft

Crew:	1 Pilot, full military gear 1 Martin/Baker ejection seat
Armament:	One internal GPU-13/A 30mm Gatling Gun
Payload:	Total payload of 10,000 lbs., to include: 1,200 rounds of 30mm anti-armor shells Laser and infrared guided weapons - AGM-144 Helfire - AGM-65 Maverick - AIM-9M Sidewinder Free-fall munitions - Mk-82 Snakeye - Mk-20 Rockeye - SUU-30B/B Cluster Bomb Rocket pods - 2.75 inch rockets - 7 and 19 round canisters
Performance:	Maximum speed of 350 kts. at SL, fully loaded Cruise speed of 250 kts. at 5,000 ft Maximum ceiling of 15,000 ft Combat radius of 400 nm Sustained 5g's at 150 kts, SL, fully loaded
Endurance:	One hour at 5,000 ft
Powerplant:	Twin engine advanced turboprop One counter rotating propeller
Groundrun:	2,000 ft groundrun, steel planking
Avionics:	All weather capability (TF/TA radar) UHF/VHF transceiver Secure voice and data link GPS capability, IFF, passive ECM
Certification:	Military - Ground Attack

2.2 Specifications for a Modest Technology Close Air Support Aircraft (the Bad)

The primary purpose of the modest technology aircraft is to provide close air support for forward troops, and engage enemy tanks and armored vehicles. The cost and complexity of the aircraft will be reduced by requiring only modest capabilities, as opposed to a "do-all" type mission. The mission specification for the aircraft is shown in Table 2.2, and the mission profile is presented in Figure 2.2.

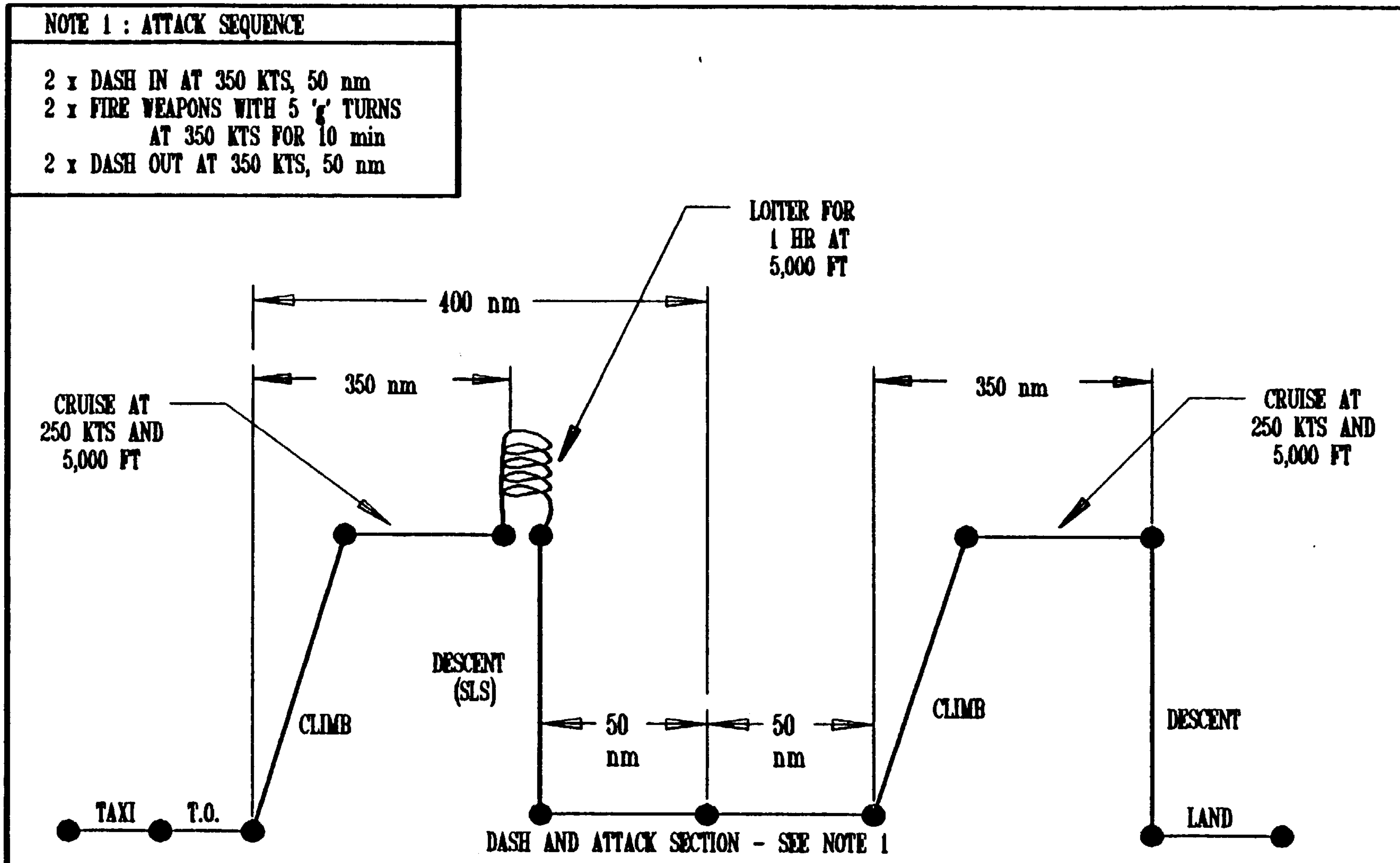


FIGURE 2.1 The Good Aircraft Mission Profile

Table 2.2 - Mission Specification for a Modest Technology Close Air Support Aircraft

Crew:	1 Pilot, full military gear 1 Martin/Baker ejection seat
Armament:	One internal GPU-13/A 30mm Gatling Gun
Payload:	Total payload of 4,100 lbs., to include: 400 rounds of 30mm anti-armor shells Laser and infrared guided weapons - AGM-144 Helfire - AGM-65 Maverick Free-fall munitions - Mk-82 Snakeye - Mk-20 Rockeye - SUU-30B/B Cluster Bomb Rocket pods - 2.75 inch rockets - 7 and 19 round canisters
Performance:	Maximum speed of 350 kts. at SL, clean Cruise speed of 250 kts. at 5,000 ft Combat radius of 120 nm Sustained 5g's at 125 kts, SL, fully loaded
Endurance:	Four hours at 5,000 ft
Powerplant:	Twin engine advanced turboprop One counter rotating propeller
Groundrun:	1,200 ft groundrun, soft field
Avionics:	Day/Night capability (TF/TA radar) UHF/VHF transceiver Secure voice and data link, IFF
Certification:	Military - Ground Attack

2.3 Specifications for a Low Cost Close Air Support Aircraft (the Ugly)

The mission of the low cost close air support aircraft is to engage enemy tanks. The aircraft will have limited avionics and payload, which will help reduce the price per aircraft. This will facilitate purchasing a large number of aircraft. These aircraft adhere to the philosophy of sending a relatively inexpensive airplane after a relatively inexpensive target. For example, what is the logic of sending a $30 million dollar airplane after a $2 million dollar tank, especially when the aircraft must destroy 30 tanks to equalize the numerical superiority (2:1) of enemy tanks to friendly air-

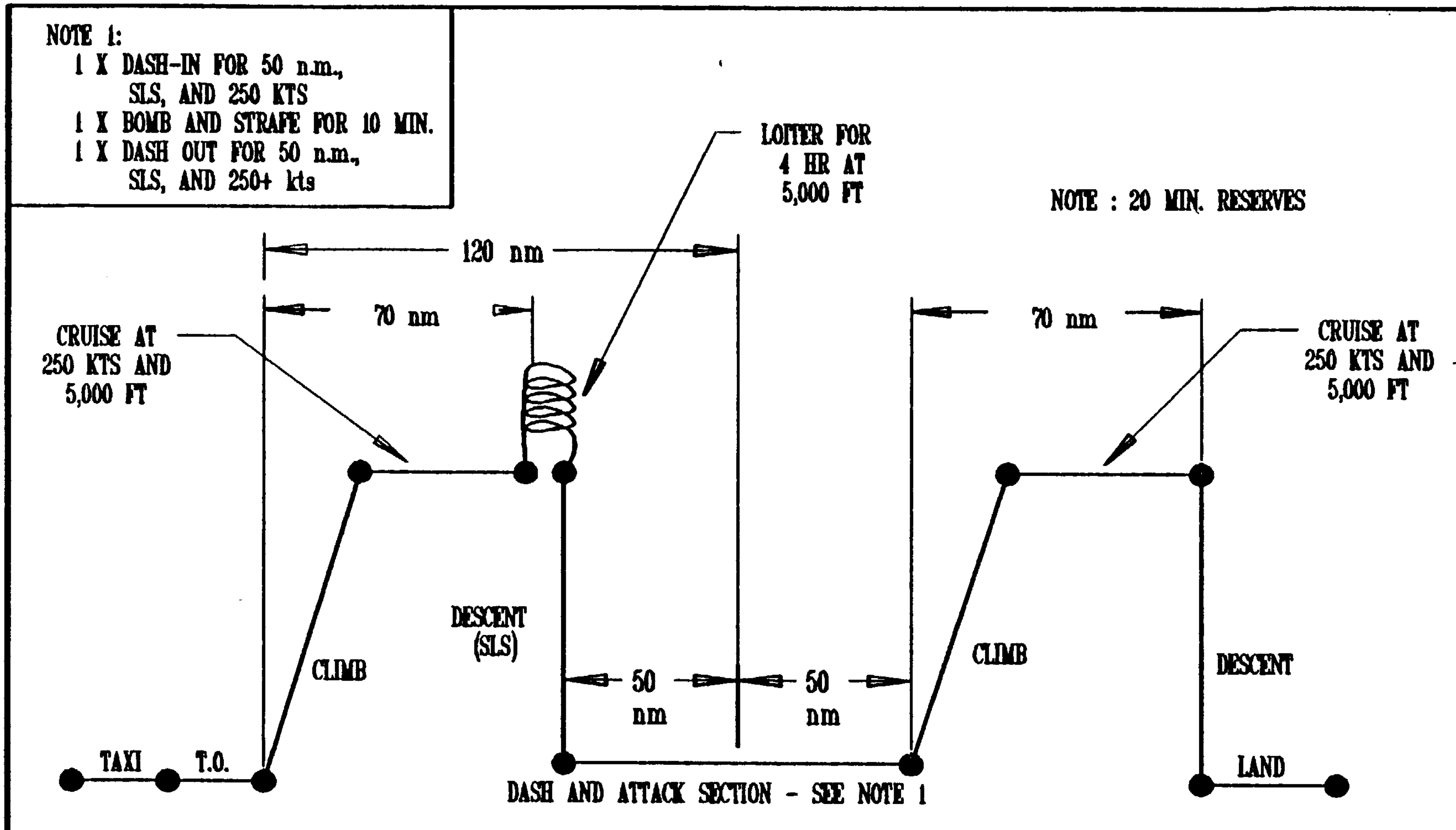


FIGURE 2.2 The Bad Aircraft Mission Profile

craft. The mission specification for the low cost aircraft is shown in Table 2.3, and the mission profile is presented in Figure 2.3.

Table 2.3 - Mission Specification for a Low Cost Close Air Support Aircraft

Crew:	1 Pilot, full military gear 1 Martin/Baker ejection seat
Armament:	One internal GPU-13/A 30mm cannon
Payload:	Total payload of 2,000 lbs., to include: 400 rounds of 30mm anti-armor shells Free-fall munitions - Mk-82 Snakeye - Mk-20 Rockeye - SUU-30B/B Cluster Bomb Rocket pods - 2.75 inch rockets - 7 and 19 round canisters
Performance:	Maximum speed of 350 kts. at SL, clean Cruise speed of 250 kts. at 5,000 ft Combat radius of 100 nm Sustained 5g's at 125 kts, SL, fully loaded
Endurance:	Four hours at 5,000 ft
Powerplant:	Single engine advanced turboprop
Groundrun:	1,000 ft groundrun, soft field
Avionics:	Day capability (IFR capabilities) UHF/VHF transceiver Secure voice, IFF
Certification:	Military - Ground Attack

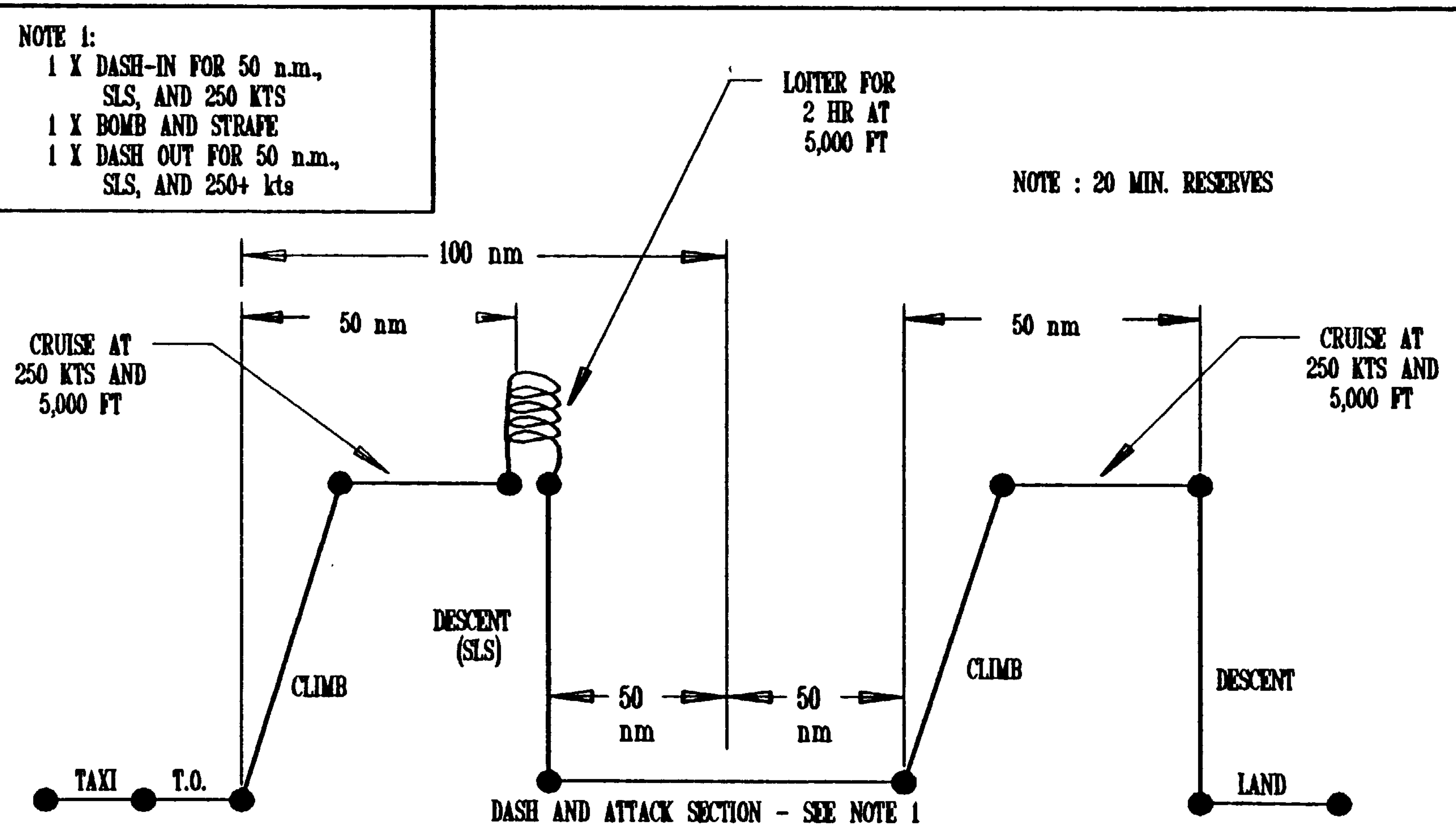


FIGURE 2.3 The Ugly Aircraft Mission Profile

3. A HISTORICAL SURVEY OF CAS AIRCRAFT

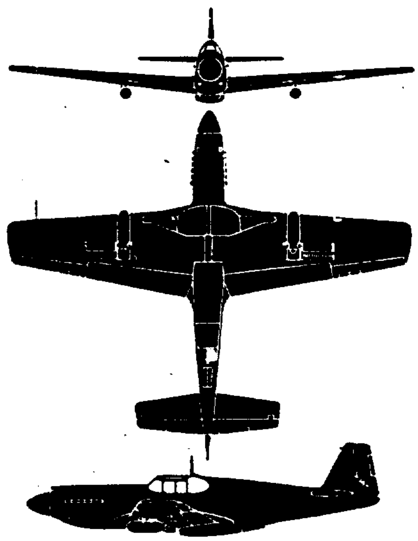
By the start of WWII, aircraft had begun to dominate the course and outcome of combat. Strategic bombers pounded cities and military targets, and fighters cleared the skies of enemy aircraft, allowing the bombers to reach their targets with some hope of returning to base. It was in WWII that the combat air support (CAS) mission was refined and developed into a deadly method of fighting. Fighters and light bombers would fly low and fast, strafing and bombing enemy troops and armor. Essentially, a CAS airplane is armed and used much like an airborne tank. In WWII, most CAS aircraft were converted fighters. These aircraft usually had internal cannons, and carried around 2000 lb of free fall bombs and rockets. They would fly low and fast, using the terrain as cover against enemy fighters and anti-aircraft guns. When they reached their targets, they would strafe and bomb, and then climb out, ready to fight their way home as fighters. The P-51 and P-47 were used extensively in this role in Europe, and the P-38 was used extensively in the North African and Italian campaigns. Both the P-38 and British versions of the P-51 were cannon armed, while the P-47 and American P-51s carried 50 caliber machine guns. These aircraft also were heavily armored and had a reputation for bringing their pilots home even after sustaining extensive battle damage. The Ju-87 and the A-36 used different tactics, however. The A-36 was an attack version of the P-51A, and was fitted with dive brakes, and the Ju-87 traded speed for armor and was dedicated to the dive bombing role. The Ju-87 could also carry two 37mm anti-tank cannons, each with 12 rounds of ammunition. These aircraft would fly to the target at medium altitudes, and then enter near vertical dives, releasing their bombs just in time to make an effective pullout. As an added touch, the Ju-87 had a siren on one of its landing gear fairings that would produce a loud wail as the airplane entered one of its dives.

Korea saw the introduction of the jet as a large component of the American fighting force. Jets did not have the endurance of the propeller aircraft, so CAS work was left to the A-1 Skyraider, the P-51 Mustang, and the AU-1 Corsair. The AU-1 was a dedicated attack version of the F-4U-6 Corsair. It could carry 4000 lb of bombs and rockets and four 20mm cannons in its wings. These aircraft spent most of their time hitting troops, bridges, and supply routes.

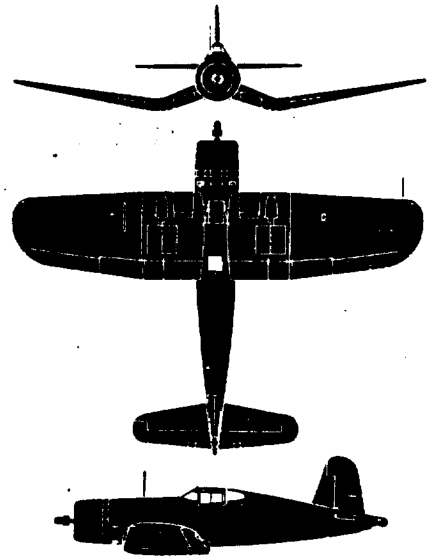
In Vietnam, the only aircraft that could successfully perform the CAS mission was the aging A-1. The attack fighters of the time, such as the F-105, were much too fast and could not stay over the battle field long enough to be useful to the ground troops. The A-1s were vulnerable to SAMs, but they were the only aircraft available for the CAS role. The A-7 Corsair II was a step in the right direction, but it was still not a true CAS airplane. Most of the CAS work toward the end of the war was being performed by helicopters which, while effective, were lightly armed.

Since Vietnam, the CAS mission has gained a few aircraft. The AV-8B Harrier can operate from forward bases, and can be an effective CAS airplane. The AV-8B version can even boast of a significant battle field endurance. Unfortunately, the Harriers must be taken to well equipped depot sites when significant engine maintenance is needed. Argentina has developed a dedicated COIN (counter insurgence) aircraft called the Pucara. The COIN mission differs from CAS only in that the target troops are not expected to have modern anti-aircraft weapons. Finally, the king of CAS aircraft is the A-10 Thunderbolt II (a.k.a. "Warthog"). The A-10 was designed to carry a heavy payload from a forward base to the battle field, loiter there for 1.5 hours, bomb and strafe as needed, and then return to the forward base even if heavily damaged. The A-10 has the unique ability to rapidly destroy tanks by either strafing or firing Maverick missiles. Since its production, the role of the A-10 has changed from CAS to pure tank-busting, but it has retained its CAS capability. The newest CAS airplane is the Soviet Frogfoot. Similar to the A-10 in size, the Frogfoot closely resembles the Northrop A-9, one of the competitors in the fly off that led to the purchase of the A-10. The Frogfoot has tank busting capabilities, but not to the degree possessed by the A-10. Instead, the Frogfoot concentrates on the ground support side of CAS. One difficulty with CAS still remains; the CAS aircraft currently in use are operated by the Air Force, not the Army. There are good reasons for this, but this causes communication difficulties, and it prevents the Army from having the aircraft that it wants. The Good, Bad, and Ugly aircraft presented here are designed to be used by the Army, and thus fill a gap in the U.S. arsenal.

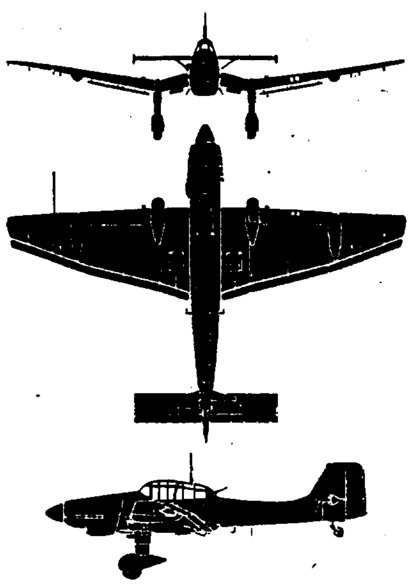
Figure 3.1 shows the threeviews of the aircraft discussed in this chapter.



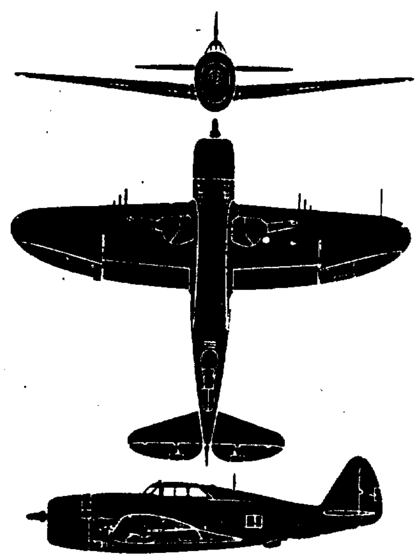
The North American A-36 "Mustang" Fighter-Bomber



The Vought F4U-1 "Corsair" Single-seat Fighter.

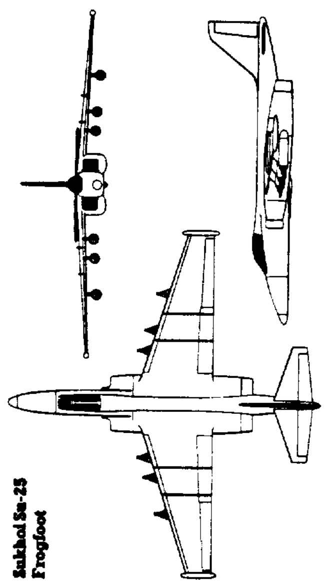


The Junkers Ju 87D Dive-Bomber.

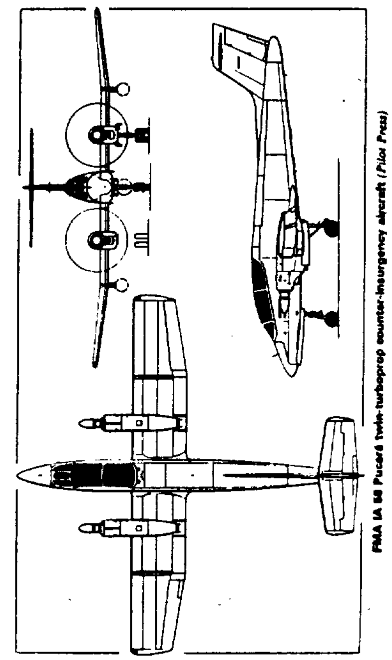


The Republic P-47 "Thunderbolt."

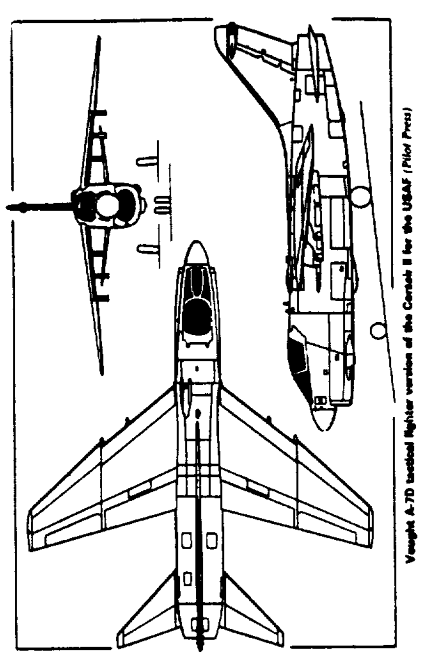
Figure 3.1a Threeviews of Close Air Support Aircraft
Copied from Reference 8



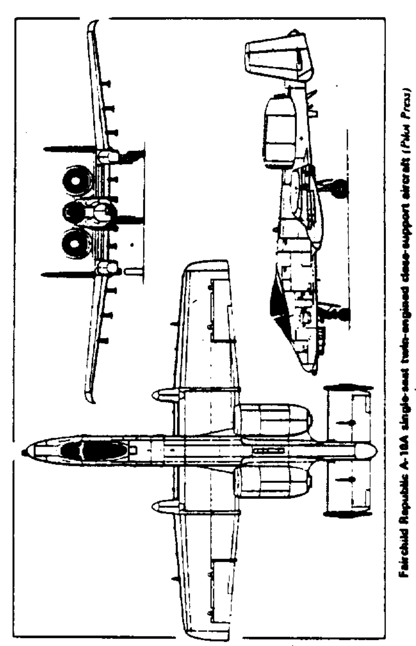
Sukhoi Su-25 Frogfoot



FMA IA 58 Pucará twin-turboprop counter-insurgency aircraft (Pilot Press)



Vought A-7D tactical fighter version of the Corsair II for the USAF (Pilot Press)



Fairchild Republic A-10A single-seat twin-engined close-support aircraft (Pilot Press)

Figure 3.1b Threeviews of Close Air Support Aircraft

Copied from Reference 8

4. CONFIGURATION DESCRIPTION

The purpose of this chapter is to present the configuration of the Good, Bad and Ugly aircraft. The following aspects will be included:

1) Overall configuration
2) Forward fuselage
3) Wing
4) Propulsion systems
5) Weapons systems
6) Landing gear

Throughout the design of each aircraft, an emphasis was placed on achieving as much commonality as possible between the aircraft, while maintaining the feasibility of each.

4.1 Overall Configuration

The threeviews for the Good, Bad and Ugly aircraft are presented in Figures 4.1 through 4.3. The major design decisions that were made are discussed in this section, along with the reasoning behind each. Commonality considerations played a crucial role in most of the design decisions. Because of the relatively large difference in take-off weight, payload and power requirements between the three aircraft, the number of configurations that would retain a high degree of commonality were limited.

The overall configuration selected for the three aircraft is of the twin boom type. The reasons behind this decision are listed below:

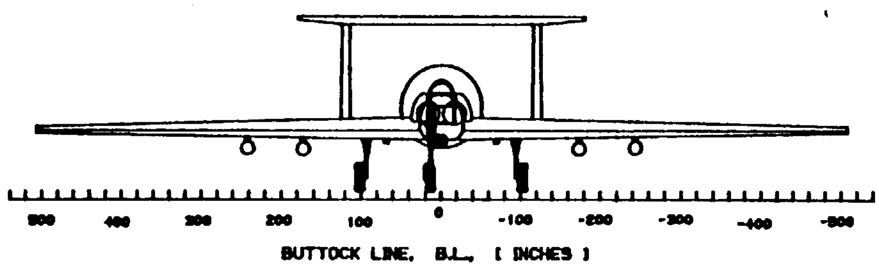
1) The engines can be mounted in a pusher configuration, closer to the center of gravity of the aircraft, giving more favorable weight and balance characteristics. Furthermore, adverse yaw due to engine-out conditions is avoided when the engines are mounted on the centerline of the aircraft.

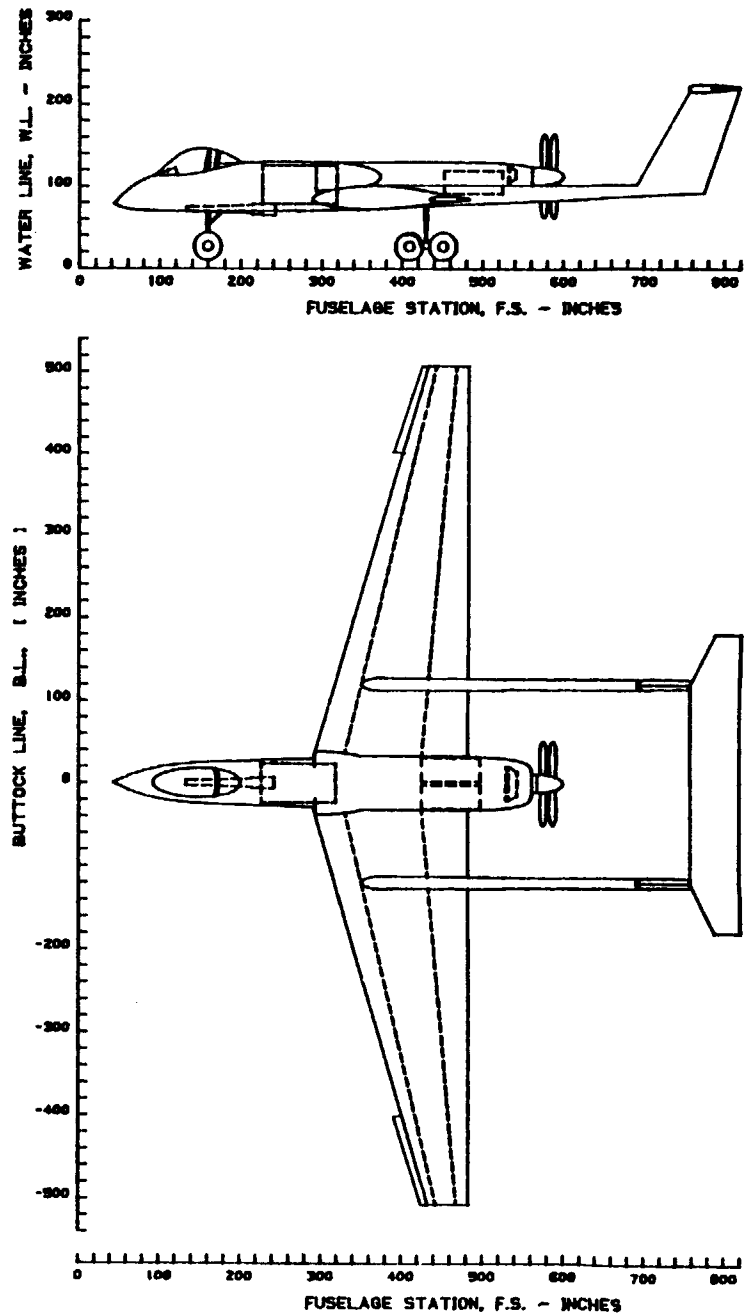
2) It is difficult for persons to run into the propeller while running up the engines on the ground.

3) A pusher configuration allows for excellent forward visibility, compared to tractor configurations. This is an important consideration for ground attack aircraft.

4) A pusher configuration allows for almost 100% commonality in the cockpit section.

5) The twin boom empennage structure allows for a high degree of commonality in the empennage surfaces as well as good survivability.

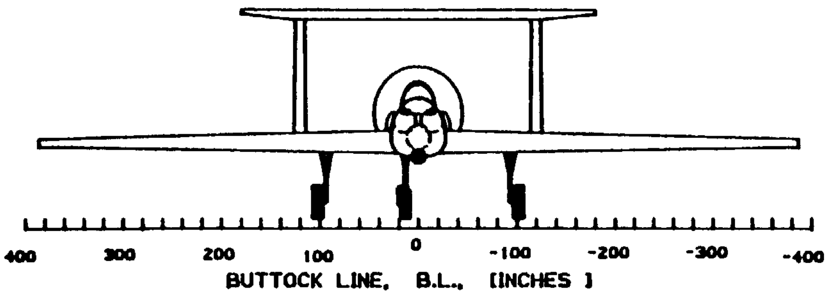


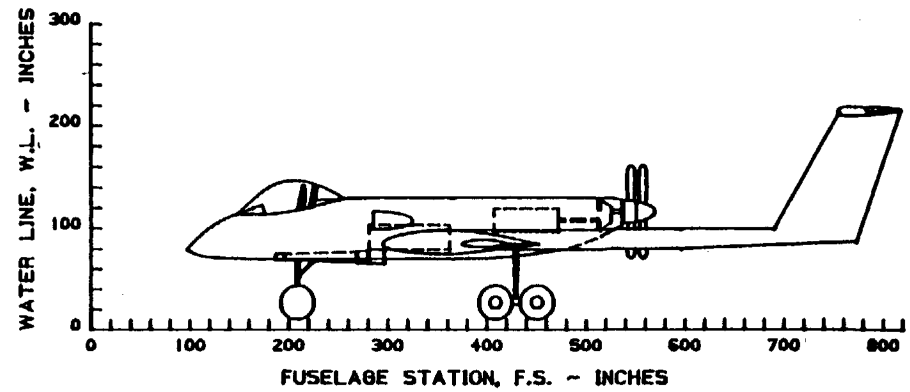


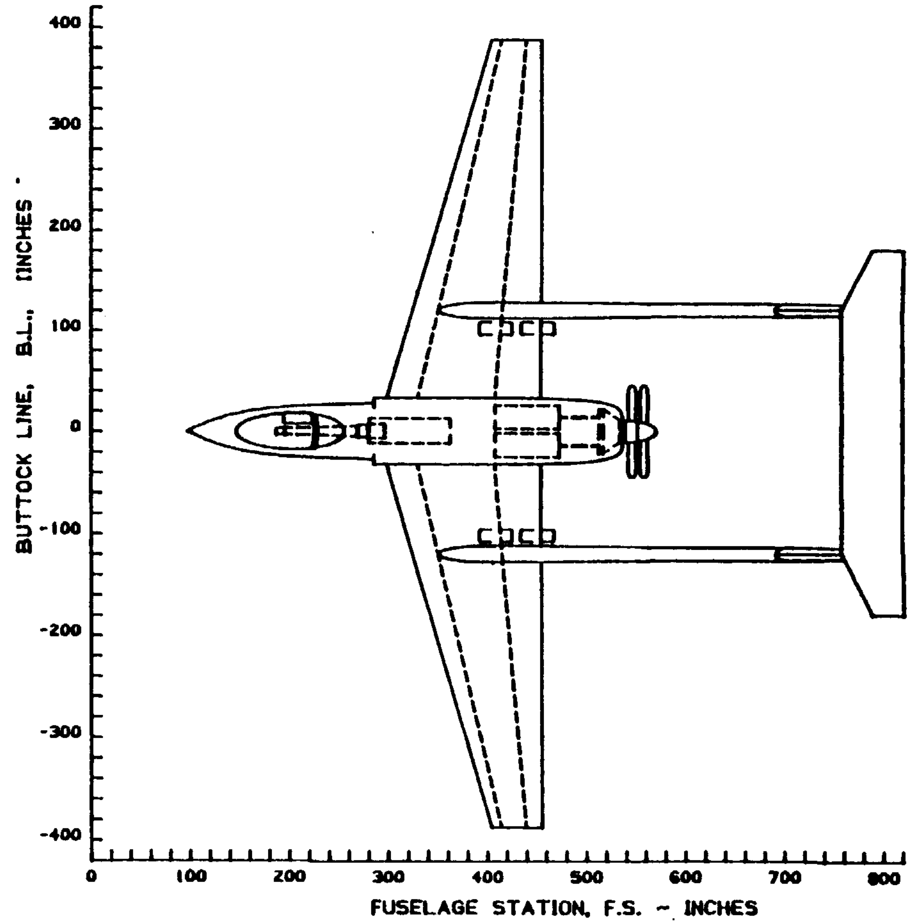
	Wing	Horizontal Tail	Vertical Tail
Area(ft^2)	890	160	2*60
Span(ft)	84.0	33	9.7
MGC(ft)	11.8	5.5	6.25
Aspect Ratio	8.0	6.8	1.6
LE Sweep(deg)	12.5	0	30
Taper Ratio	0.25	1	.7

Weight	
Take-off (lb)	39,725
Empty (lb)	20,726
Fuel (lb)	10,200
Payload (lb)	10,000
TO Power (hp)	12,000
TO Wing Loading (lb/ft^2)	44.6
TO Power Loading(lb/hp)	3.31

Figure 4.1 Threeview for the Good Aircraft



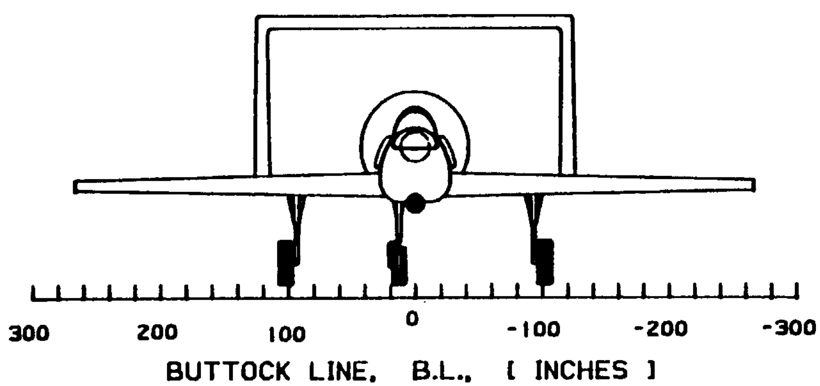


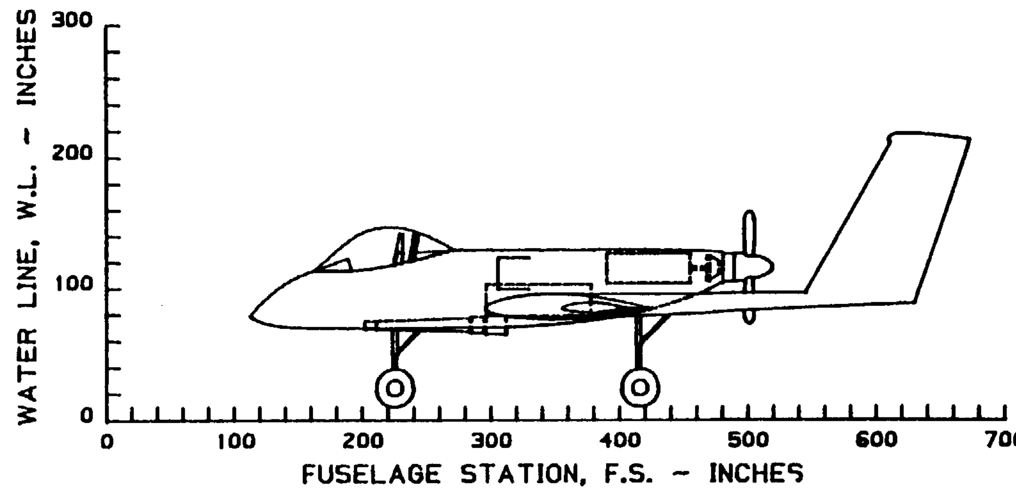


	Wing	Horizontal Tail	Vertical Tail
Area(ft^2)	577	160	2*60
Span(ft)	64.0	33	9.7
MGC(ft)	9.8	5.5	6.25
Aspect Ratio	7.2	6.8	1.6
LE Sweep(deg)	12.5	0	30
Taper Ratio	0.31	1	.7

Weight	
Take-off (lb)	22,289
Empty (lb)	12,457
Fuel (lb)	5,030
Payload (lb)	4,100
TO Power (hp)	5,000
TO Wing Loading (lb/ft^2)	38.6
TO Power Loading(lb/hp)	4.46

Figure 4.2 Threeview for the Bad Aircraft





	Wing	Horizontal Tail	Vertical Tail
Area(ft^2)	335	110	2*60
Span(ft)	44.0	20	9.7
MGC(ft)	8.0	5.5	6.25
Aspect Ratio	5.9	3.6	1.6
LE Sweep(deg)	12.5	0	30
Taper Ratio	0.39	1	.7

Weight	
Take-off (lb)	10,935
Empty (lb)	7,237
Fuel (lb)	1,750
Payload (lb)	2,000
TO Power (hp)	2,000
TO Wing Loading (lb/ft^2)	32.6
TO Power Loading(lb/hp)	5.46

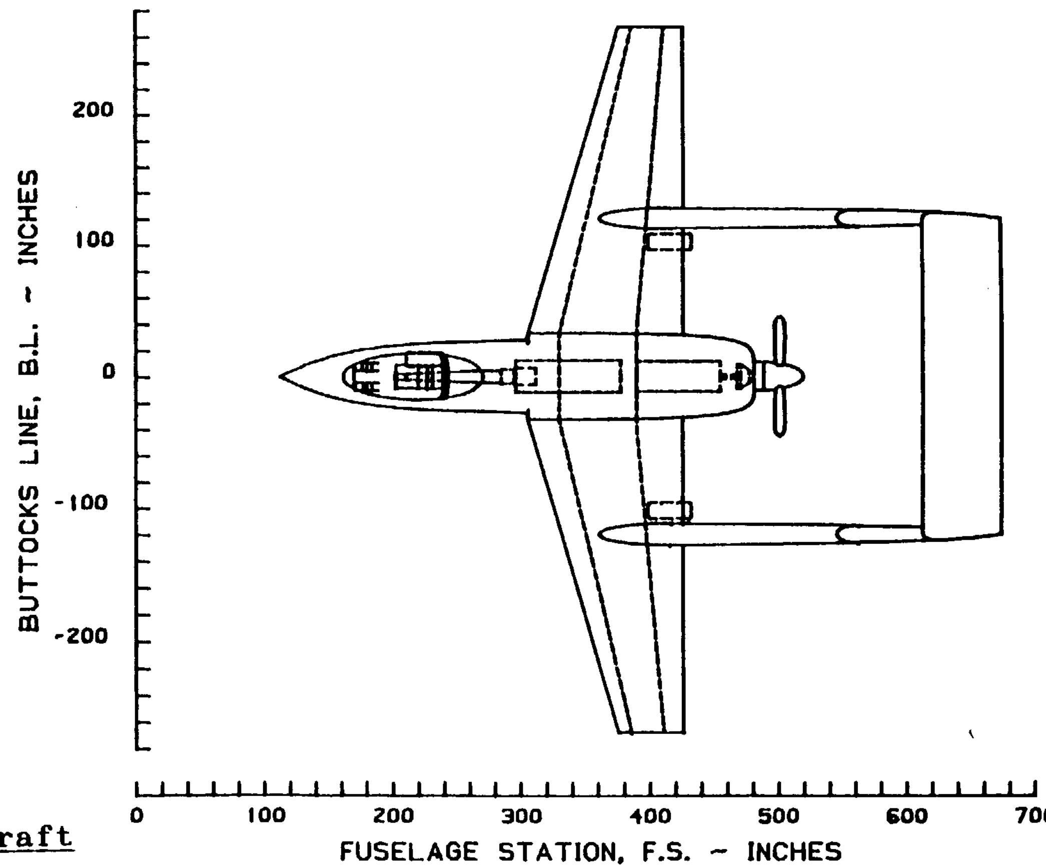


Figure 4.3 Threeview for the Ugly Aircraft

Basic inboard profiles for each of the three aircraft are presented in Figures 4.4 through 4.6. The cockpit section and nose landing gear arrangement is common for the three aircraft. The 30 mm Gatling gun is located aft of the nose gear. It is placed at an angle such that the barrel that is firing is along the centerline of the aircraft, facilitating sighting. A 1,200 round drum is used for the Good aircraft, while the Bad and Ugly have 400 round drums.

The fuselages of the aircraft are divided into three separate sections:

1) Forward section: cockpit, nose gear, radar
2) Middle section: wing/fuselage intersection
3) Aft section: engine installation

The forward fuselage section of the three aircraft consists primarily of the cockpit, nose gear, and necessary avionics. It is common between the Good, Bad and Ugly. The size of the cockpit section was dictated by the need to accommodate the advanced avionics systems and radar of the Good aircraft. Nose gear stowage volume also impacted on the design of the forward section.

The middle section is different for each aircraft. However, all three retain the same cross section, which is dictated by the diameter of the ammunition drum of the Good airplane. The length of the fuselage varies between the three, though the wing/fuselage intersection is common.

The aft fuselage section is the same for the three aircraft. The size of this section is determined by the engine volume specifications for the Good airplane. Because the avionics and powerplant for the Bad and Ugly occupy less space than for the Good aircraft, the two smaller aircraft do not utilize all the space available in the aft fuselage section.

The design of the empennage was determined by the selection of the twin boom configuration. As shown in Figures 4.1 through 4.3, the three aircraft have common vertical tails and horizontal tail bars, located above the vertical tails. This ensures that the empennage is kept out of the prop-wash. Although this location reduces the effectiveness, it will increase the fatigue life of the structure. The Good and Bad have horizontal tail fins extending from the horizontal tail bar to increase the tail area.

The tail booms have been sized to account for:

1) Necessary empennage support strength
2) Landing gear size and stowage
3) Commonality

The Good and Bad use a common boom. The aft portion of the

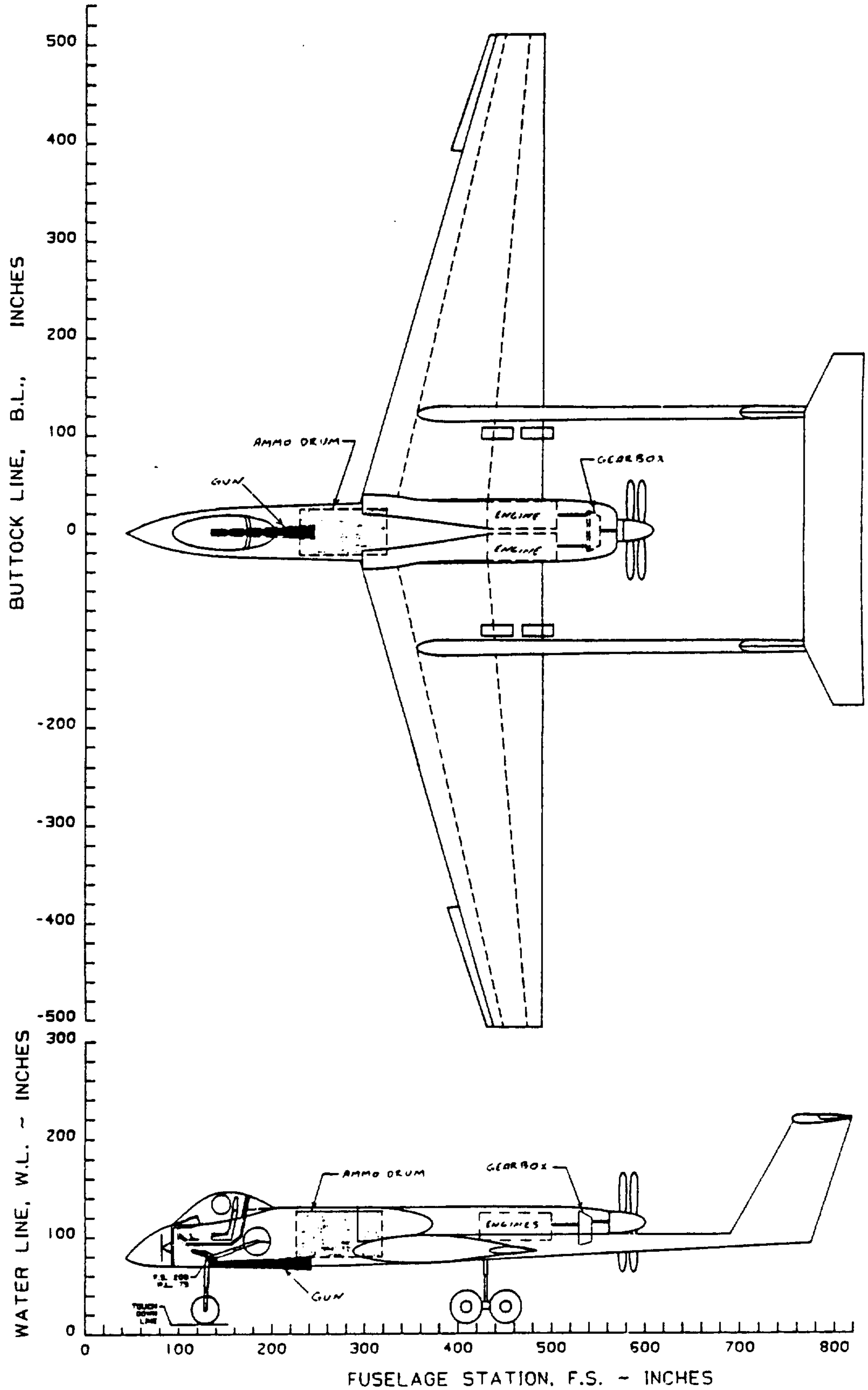
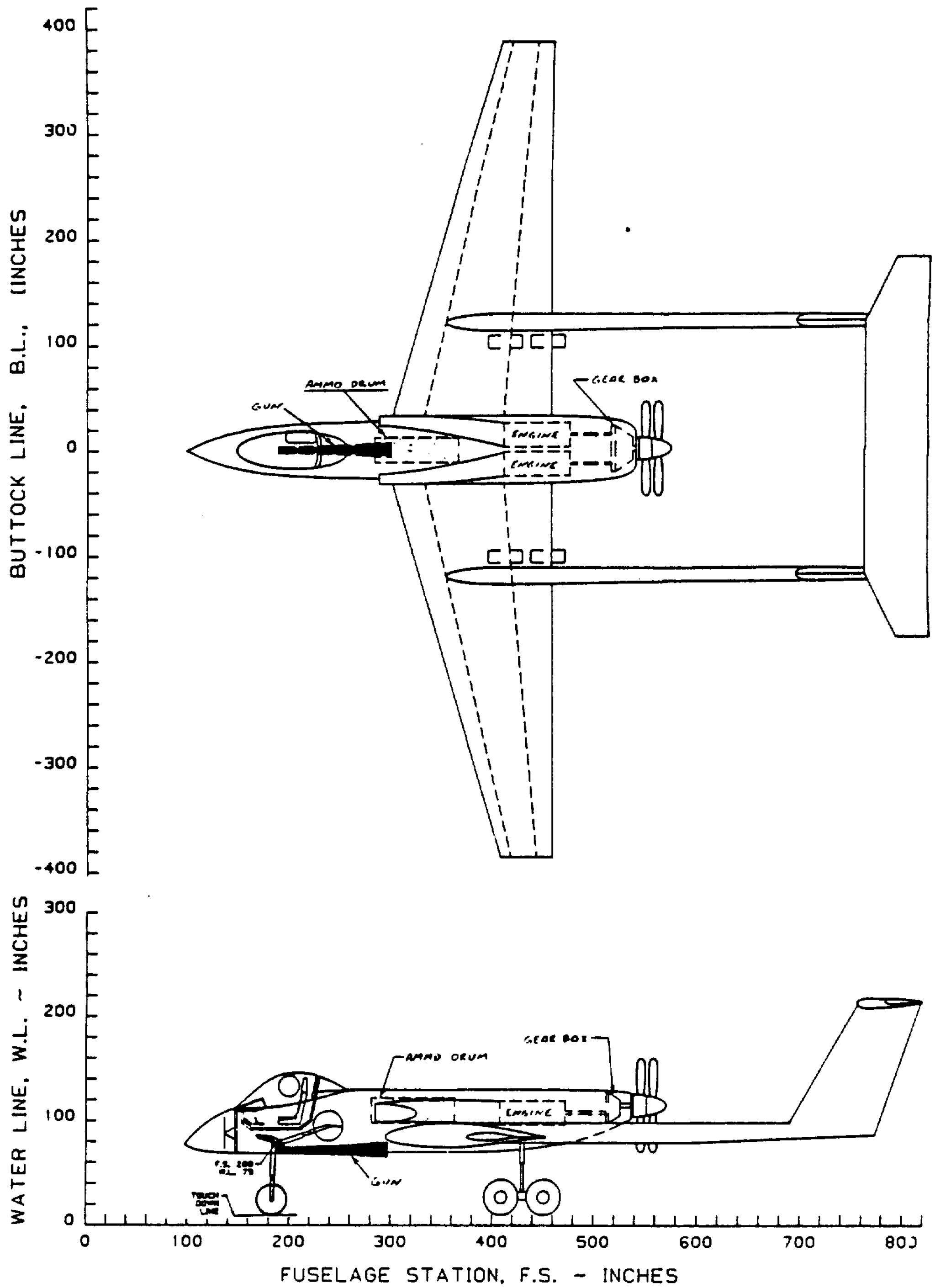
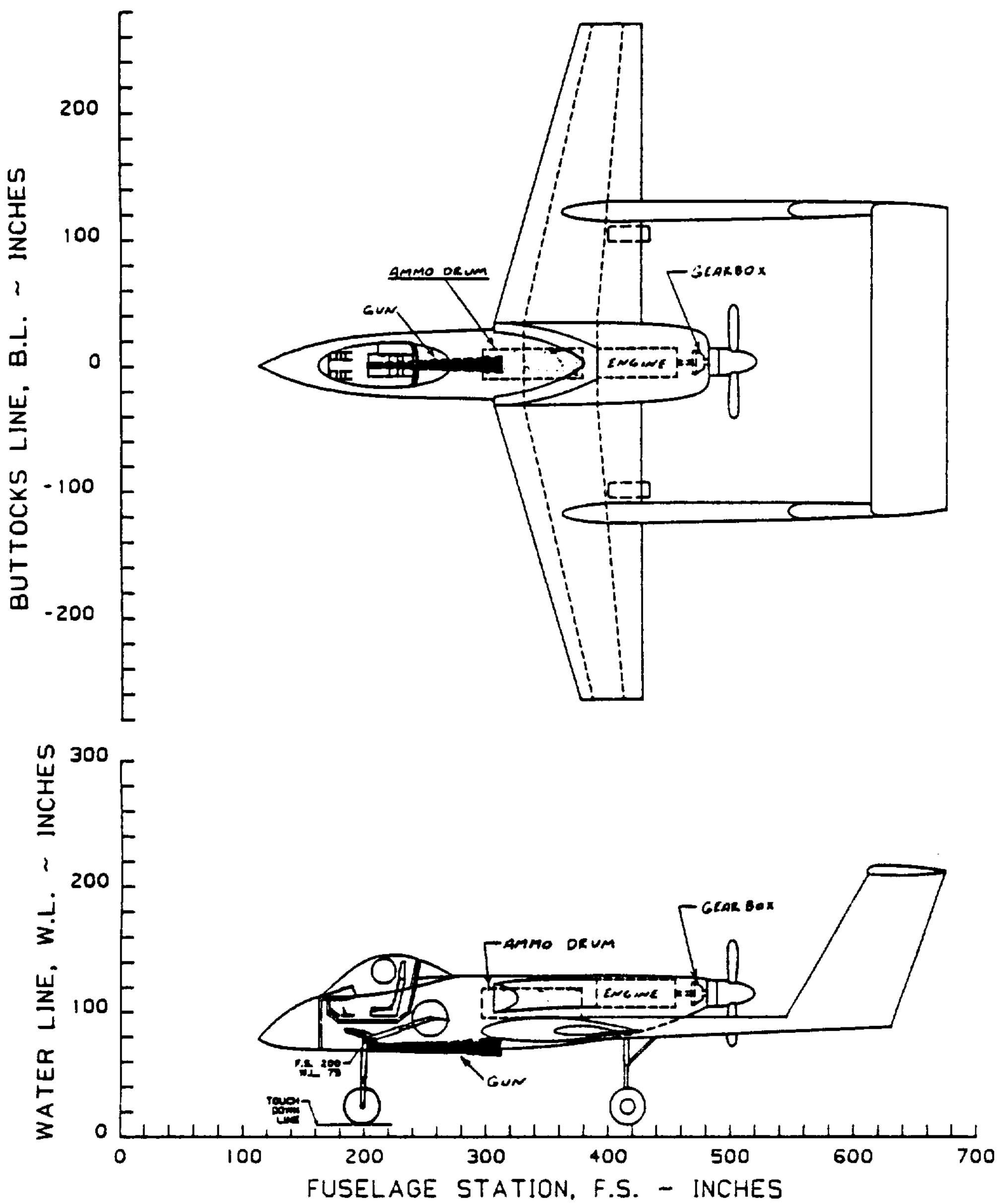


Figure 4.4 Inboard Profile for the Good Aircraft



<u>Figure 4.5 Inboard Profile for the Bad Aircraft</u>



<u>Figure 4.6 Inboard Profile for the Ugly Aircraft</u>

booms is used on the Ugly also. The boom attachment points, located ten feet on either side of the aircraft centerline, are also common for the three aircraft. Although this type of structure imposes a weight penalty on the Bad and Ugly aircraft, the benefit to commonality is viewed as substantial.

4.2 Forward Fuselage

The forward fuselage is common to all three aircraft and is shown in Figure 4.7. The size of the cockpit section was determined primarily from the volume requirements of the Good airplane. Among these volume requirements was the necessity to accommodate a radar dish and other advanced avionics in the forward fuselage. The cannon was positioned under the fuselage on the centerline. This location allows the pilot to simply aim at a target at any distance and achieve a maximum probability of destroying it. The centerline position also eliminates any adverse yawing moment which may occur while firing the gun. Positioning the gun under the fuselage also helps avoid gun exhaust gases from being sucked into the engine inlets. This positioning also prevents the pilot from being blinded when the cannon is fired at night.

The escape system consists of a Martin Baker Mark 11 ejection seat. This ejection seat was designed specifically for use in turboprop aircraft.

4.2.1 Visibility

A high degree of visibility was a major concern in the design of a family of close support aircraft. The following visibility requirements were determined for these aircraft:

1) 20 deg down over the nose
2) 45 deg down over the sides
3) 5 deg down over the back
4) Unlimited visibility above

By utilizing these values, it was determined that an F-16-type canopy would be the most suitable. To determine if the visibility requirements were met by an F-16 canopy, a visibility pattern was constructed. By assuming that the pilot has one eye at the location shown in Figure 4.7, the angles for the visibility pattern were determined. Figure 4.8 shows this pattern for the Good, Bad and Ugly.

4.2.2 Cockpit Instrumentation and Avionics Systems

The main system concept is to provide a high degree of integration between the various systems. The result is a combined system that reduces pilot workload, enhances the mission effectiveness, and improves the overall aircraft performance and reliability.

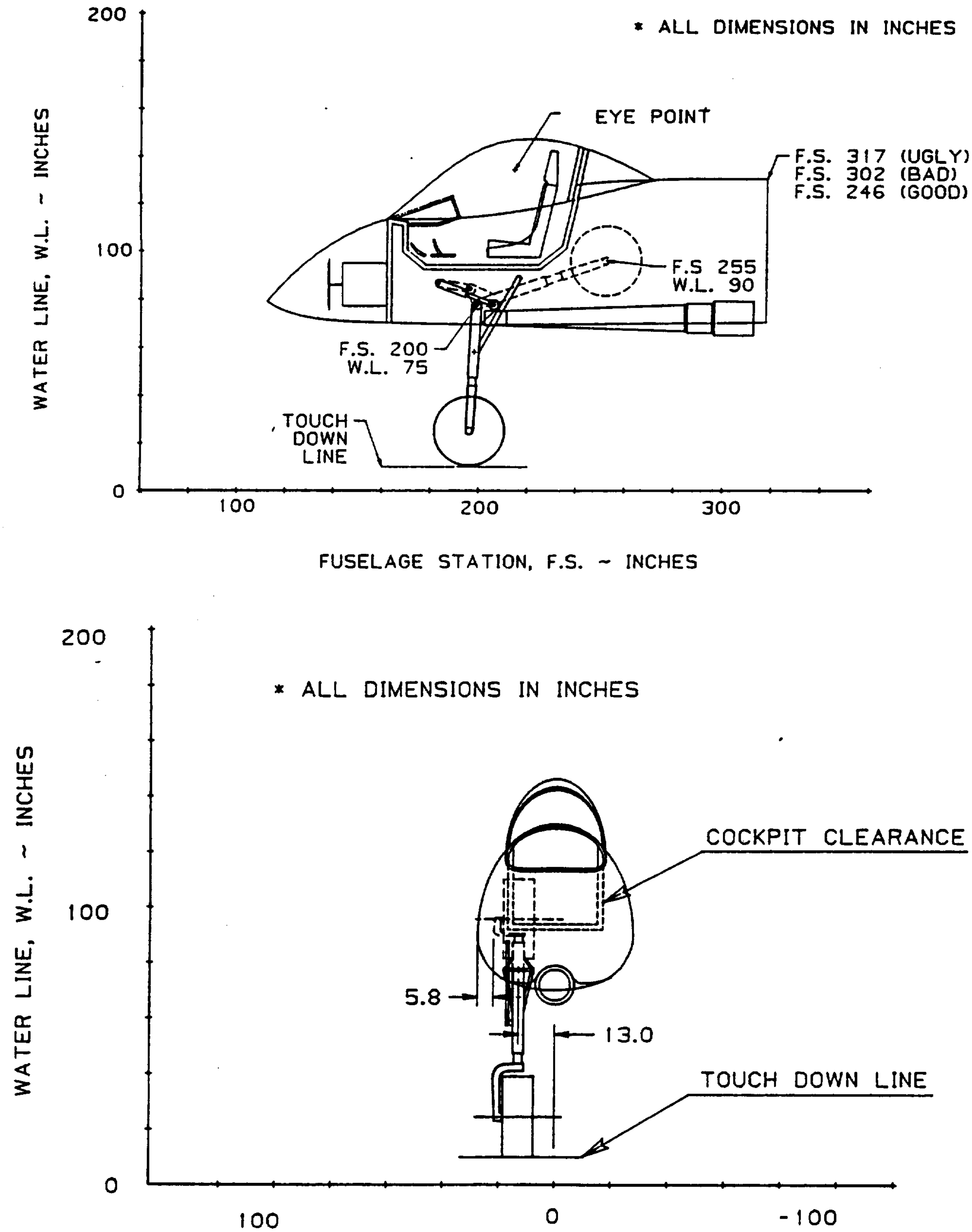


Figure 4.7 Forward Fuselage

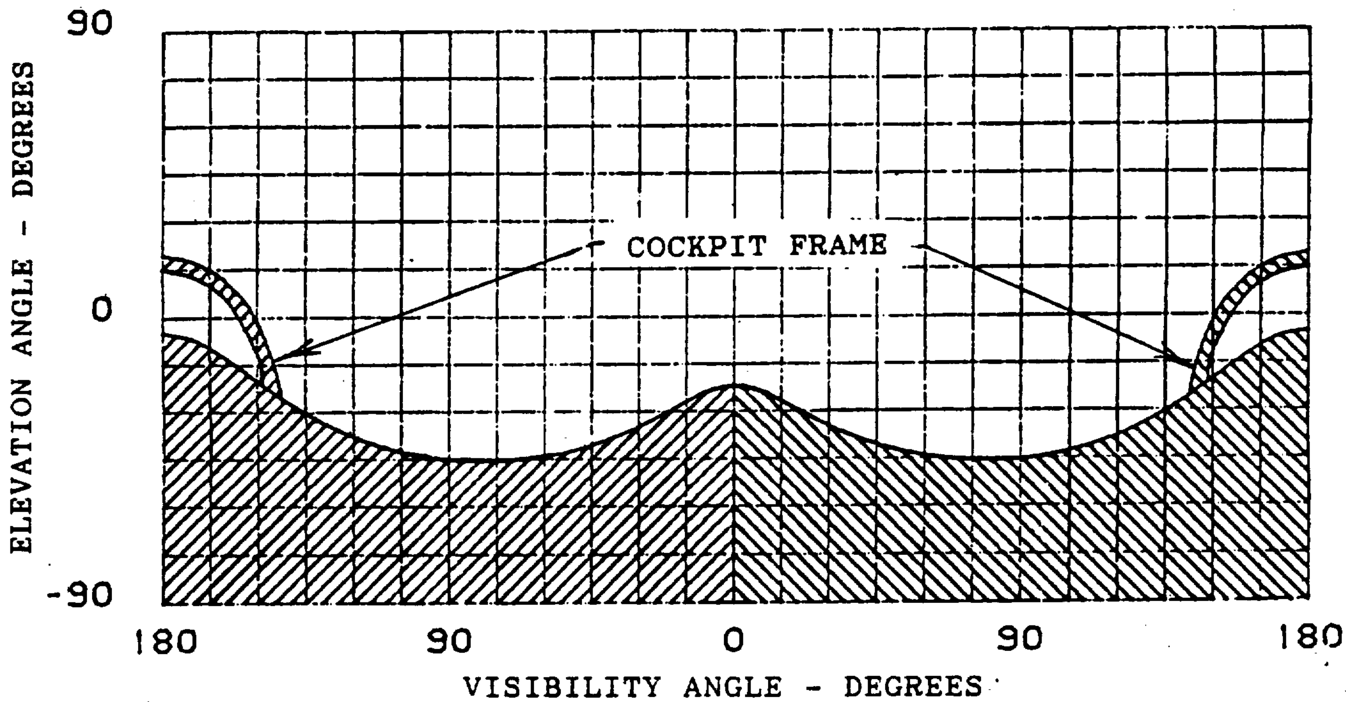


Figure 4.8 Visibility Pattern of the Pilot

The main effort in the design of the cockpit instrumentation is to útilize a minimum of controls, reducing the pilot workload.

In addition, control must be provided for the array of radio and communications equipment, propulsion system, weapons, and HUD selection.

Communications equipment comprises a major portion of cockpit equipment in modern day fighters, and should be kept to a minimum. The following communications equipment is the minimum included in the three aircraft:

1) UHF/VHF transceiver with main and standby modes
2) Secure voice and data link
3) Voice actuation for communication control

The sensors incorporated in these aircraft are also kept to a minimum. The following sensors are included:

1) Barometric and radar altimeters
2) Attitude and heading reference system
3) Navigation sensors
   a) Inertial Navigation System
   b) Global Positioning System
   c) Terrain Referenced Navigation System (TRNS)
4) Forward looking infra-red (FLIR) and/or night vision goggles (NVG)
5) Radar for target acquisition and Search/Track for Good and Bad aircraft

The actual display involves a combination of HUD and Heads Down Display (HDD). The HUD is used to display information pertaining directly to the outside world. The HUD incorporates an advanced system involving a projection that wraps around the pilot. The images are projected on the canopy. A diagram of this proposal is provided in Figure 4.9.

The HDD presents the information not directly related to the outside world. This will include targeting and weapon status, and map representations displayed on two CRT's. Reference 6 presents the avionics and cockpit instrumentation layout in greater detail.

The cockpit design included the following items:

1) Advanced HUD (Canopy Projection)
2) Weapons selection and activation switch panel
3) HUD switch panel
4) FLIR/Night vision switch panel
5) 8" x 8" CRT for map presentation
6) 8" x 8" CRT for weapon status and other information
7) Side stick controller and rudder pedals
8) Manual landing gear actuation
9) Throttle
10) Engine start and control switch panel

Through the use of advanced cockpit systems, the pilot is allowed to concentrate on flying the aircraft and successfully completing the mission.

4.3 Wing

The primary considerations in designing the wing planforms for the three aircraft were aerodynamic performance and commonality. All three aircraft use NACA 64A215 airfoils for the wings. The design of the wings, as shown in Figure 4.10 is as follows:

1) Constant 12.5 degree leading edge wing sweep.

2) The outboard section of the wing is the wing of the Ugly and is common to all three aircraft. The wings of the Bad and Ugly are obtained by adding additional sections to the wing of the Ugly.

3) To avoid tip stall behavior due to the low taper ratios of the wings, a snag is incorporated in the design of the Good.

All three aircraft have plain flaps, extending from the wing/fuselage intersection to span section 0.55. Advantages of plain flaps include simplicity of operation and ease of maintenance.

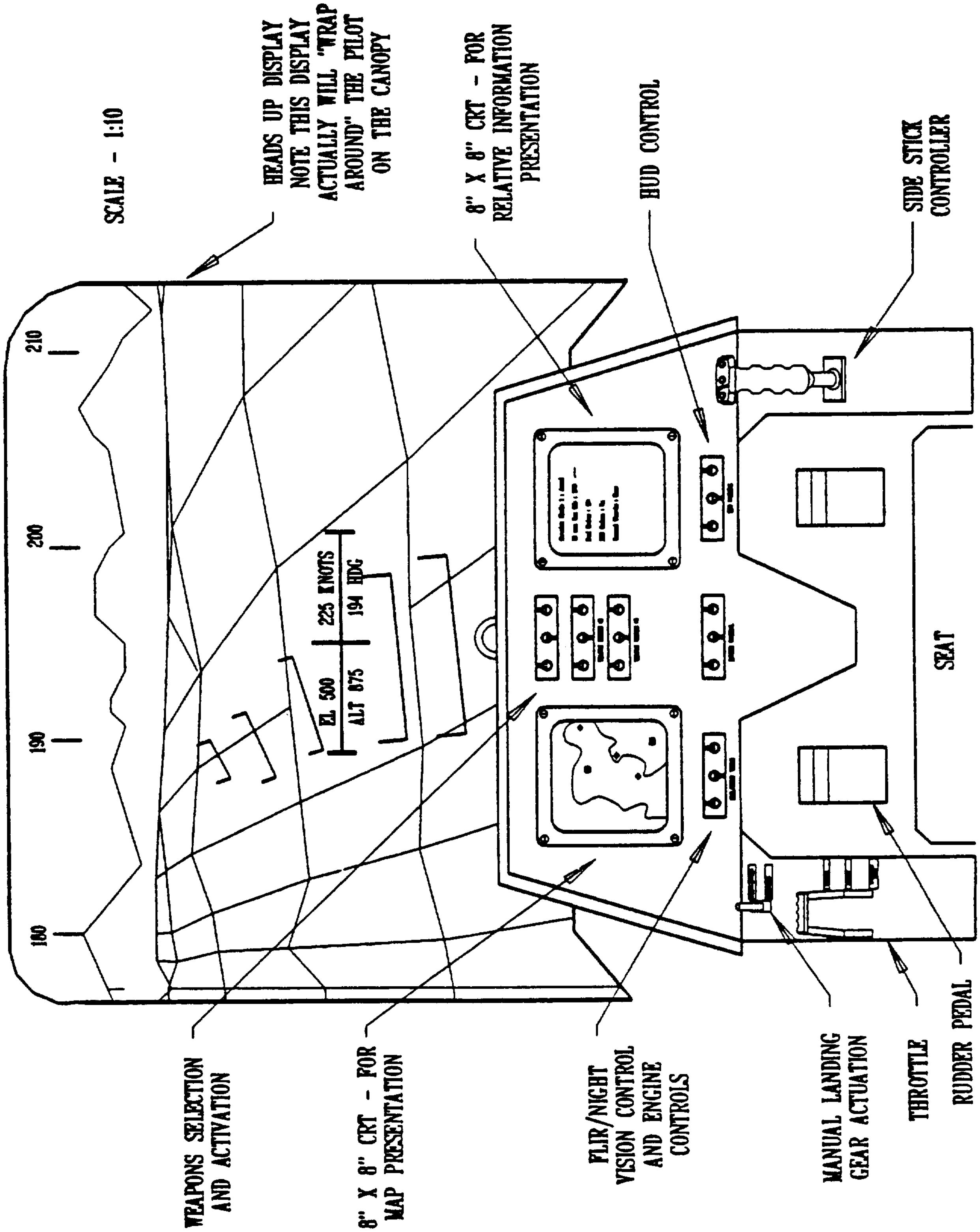


Figure 4.9 Cockpit Layout

	GOOD	BAD	UGLY
AREA	890	577	335
SWEEP	12.5	12.5	12.5
TAPER	.25	.31	.39
ASPECT	8	7.2	5.9
T/C	.15	.15	.15

NOTES:

① TORQUE BOX SPARS AT .20 AND .70 CHORD

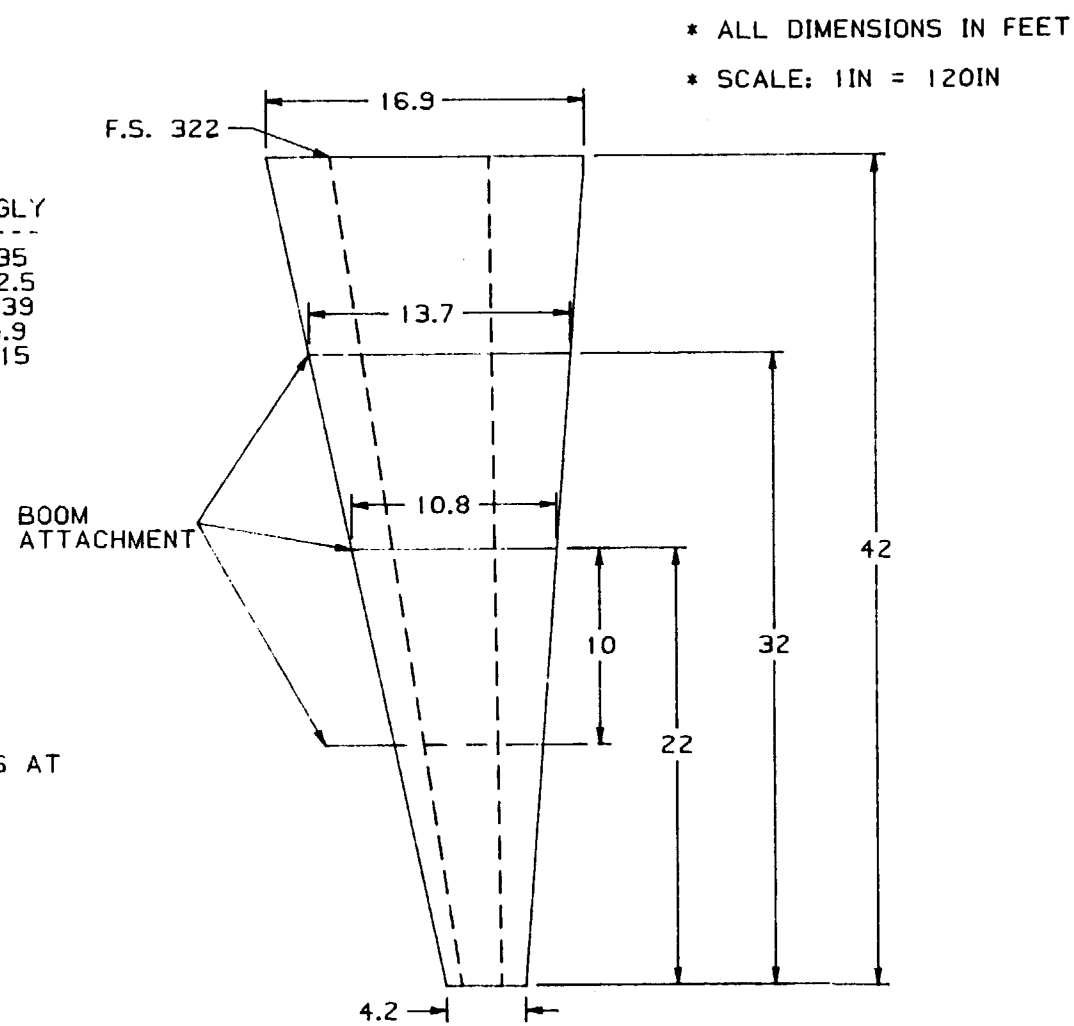


Figure 4.10 Wing Planform Design

The Good, Bad and Ugly have a cantilever, low-wing installation. This design was guided by the following considerations:

1) A shorter landing gear length compared to a mid or high wing installation. Due to the soft field requirements of the Bad and Ugly, this results in a significant landing gear weight savings.

2) Easier mounting of under wing stores in unprepared, forward operating areas. The luxury of weapons carts to hoist the under wing stores may not be available in the staging areas for the Bad and Ugly.

4.4 Propulsion System

4.4.1 Powerplant

The Good, Bad and Ugly are all powered by advanced turboprop engines, and have the following power requirements:

1) Good: 12,000 shp
2) Bad: 5,000 shp
3) Ugly: 2,000 shp

A turboprop powerplant was selected for all three aircraft based on the following conclusions:

1) Provides best overall efficiency for given cruise speed and range
2) Low weight-to-power ratio
3) Small frontal area
4) Availability of a large number of turboprops in the 2,000 to 12,000 shp range

To provide a measure of commonality in the design, the Bad and Ugly utilize the same powerplant. The Bad has two 2,500 shp engines installed side-by-side, while the Ugly has a single 2,500 shp engine. The Good uses two 6,000 shp engines and incorporates the same installation as the Bad. The use of two engines enhances the survivability of the Bad and Good. The powerplant layouts for the Good, Bad and Ugly are shown in Figures 4.11 and 4.12.

The engine(s) are buried in the aft part of the fuselage for several reasons:

1) The buried engine installation does not require pods or nacelles, reducing radar cross sectional area.
2) A buried engine installation reduces the profile drag associated with pods or nacelles.
3) The aft end of the fuselage is sized by the aircraft with the largest engine displacement, allowing a common aft fuselage shell for the two remaining aircraft.

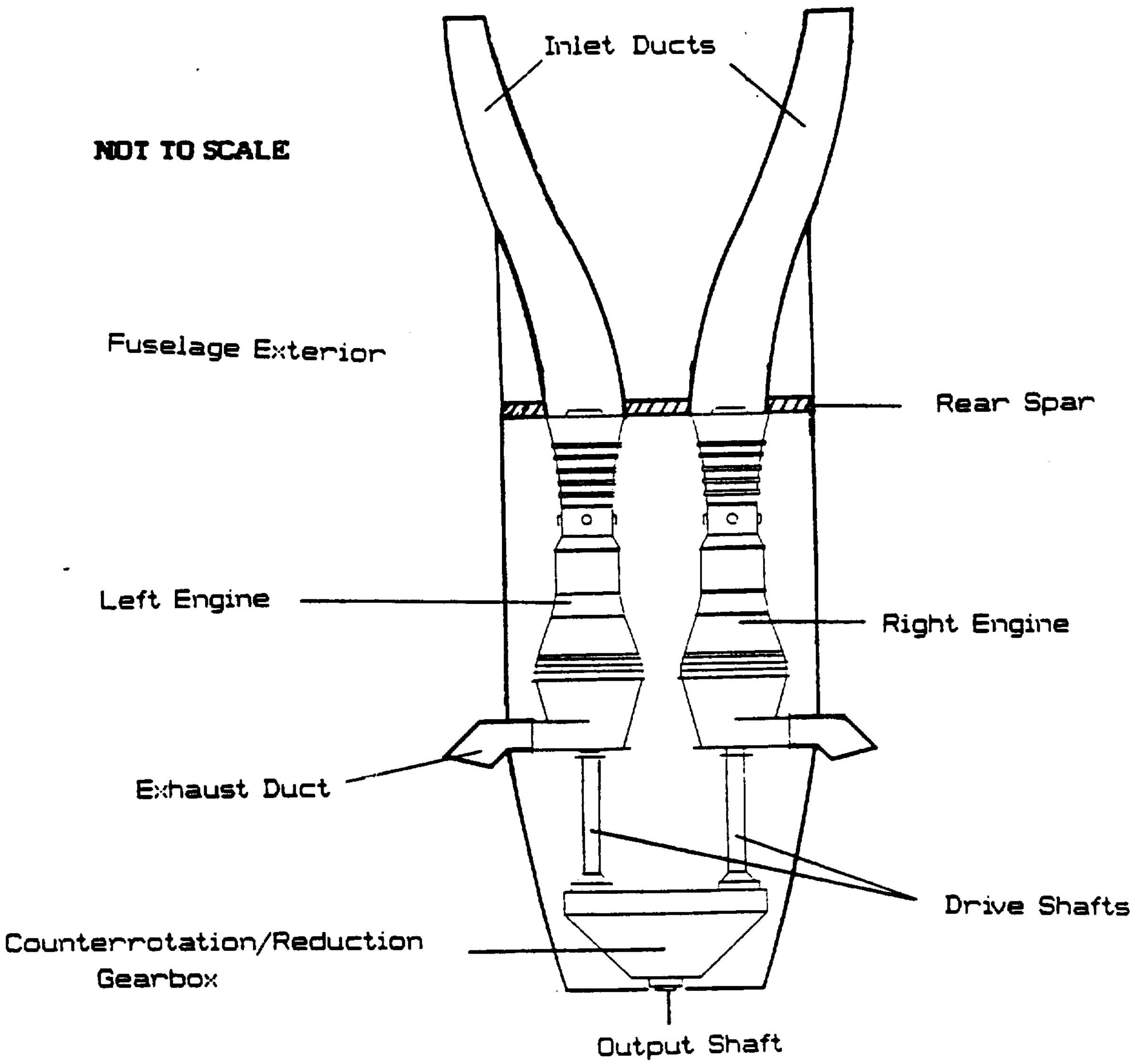


Figure 4.11 Engine Layout for the Good and Bad

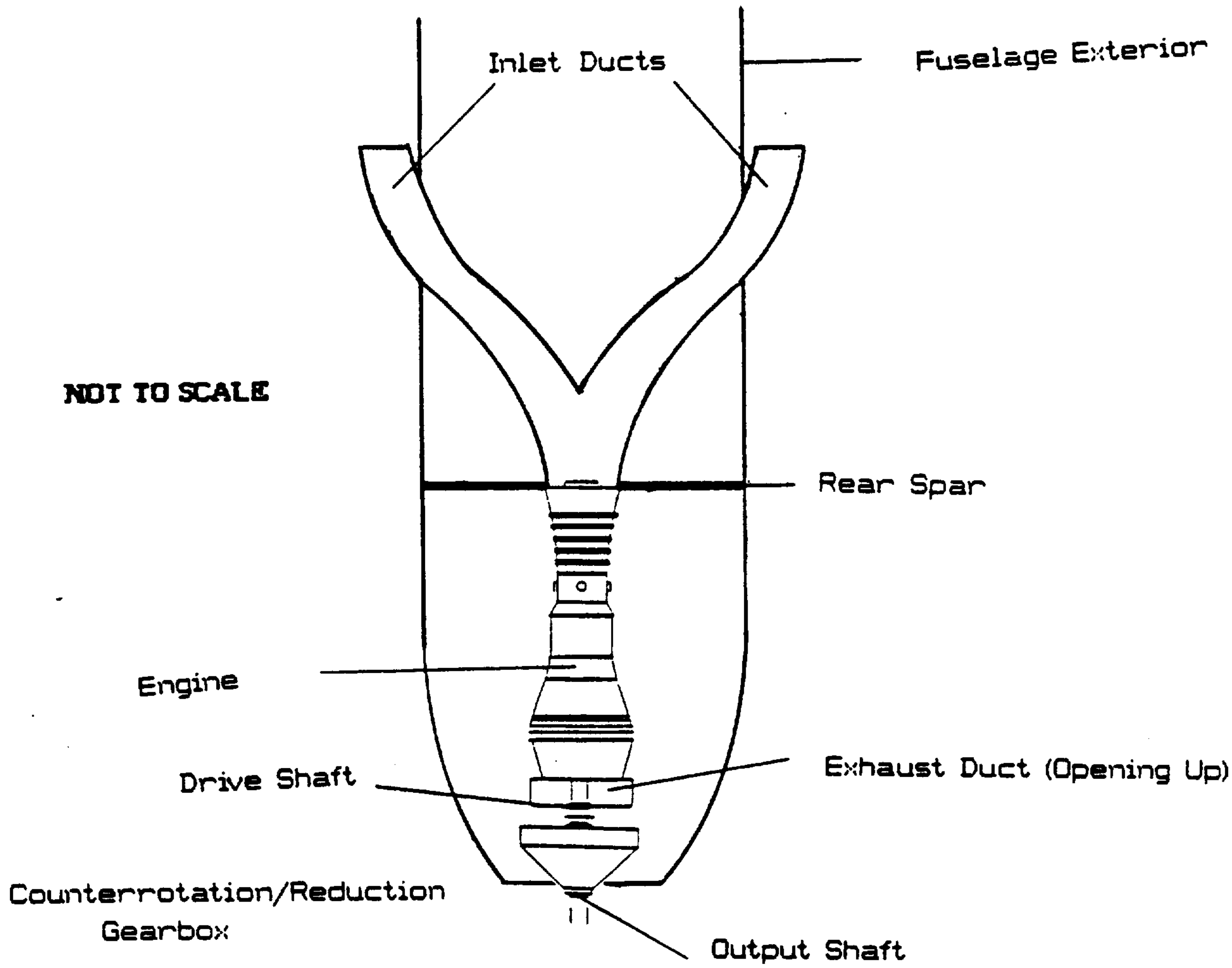


Figure 4.12 Engine Layout for the Ugly

4) The pusher installation eliminates any potential interference between the 30 mm gun and the propeller.

Since the Bad and Ugly will operate from the same base of operations, the use of identical engines decreases the required parts inventory and allows for cannibalizing.

The data for the propellers for the Good, Bad and Ugly is presented in Table 4.1. The Good and Bad use counter-rotating propellers. These not only offer higher overall propulsive efficiency, but also twin engine reliability with no adverse yaw due to engine out. However, the gearboxes needed increase the complexity of the drive system and are very heavy. The Ugly is driven by a single propeller.

Table 4.1 Propeller Geometric Data

	Diameter (ft)	No. of blades	Efficiency (Cruise)
Good	8.18	2 x 6	0.86
Bad	7.10	2 x 6	0.81
Ugly	7.10	1 x 6	0.78

The propellers will be of composite construction to save weight, but will be metallized on the shanks where the hot engine exhaust impinges on them. The propellers for the Bad and Ugly are common, though this causes a 6% loss in efficiency for both aircraft.

The design and location of the exhaust must be placed with the following design criteria in mind:

1) The exhaust does not interfere with or add heat to the gearbox
2) Provide anti-icing with exhaust
3) Exhaust parallel to stream to reduce excess interference drag

Due to the pusher configuration, it is necessary to duct the exhaust around and away from the gearbox.

4.4.2 Engine Removal

The Good and the Bad aircraft each have two engines in the upper portion of the aft fuselage. This portion of the fuselage is common to both aircraft, so the engine removal must be the same for both aircraft. The method used for the Ugly airplane will be similar to that of the other aircraft, but the Ugly airplane has only one engine and a different internal structure. The removal procedure given below is for the Good and Bad airplanes only, and the man hour estimates are conjectural for ideal conditions.

Procedure:		Man Hours
1.	Remove inboard flap sections.......	0.17
2.	Open all access doors to the upper and lower engine bays........	0.08
	- This will require ladders.	
3.	Position the crane around the engine section, secure the crane, and lower the walkways.............	0.25
	- This will require a tractor.	
4.	Remove all engine/airframe non-structural connections.........	0.25
5.	Hook the wench hooks to the engine removal lugs and remove wench chain slack............................	0.10
6.	Unbolt the engine from the airframe and wench out of the fuselage......	0.25
7.	Bolt the engine to the crane and secure the wench..................	0.10
8.	Fold up walkways and remove the crane.............................	0.10
9.	Close and secure access doors......	0.08
10.	Replace flaps......................	0.17

Engine replacement uses the same method, but steps 4-7 are in reverse order and opposite manner.

Time to remove/replace 1 engine: 1.6 Man Hours
Time to remove/replace 2 engines: 2.3 Man Hours

The crane used in this method will also work for the Ugly airplane. Figures 4.13 through 4.15 show the engine removal procedure and equipment for the Good and Bad airplanes.

4.5 Weapons Systems

The Good, Bad and Ugly are designed to be very versatile, carrying out several different missions. These are:

1) Tank Attack (Good, Bad and Ugly)
2) Ground Support/ Attack (Good, Bad and Ugly)
3) Helicopter Attack (Good)

The weapon loadings for these missions are shown in Figures 4.16 through 4.18.

All three aircraft incorporate a GAU-13/A 30mm gatling gun. It is a four-barrel light weight derivative of the GAU-8/A used on the A-10. It can fire either Armor Piercing Incendiary (API) or High Explosive Incendiary (HEI). This cannon offers several advantages:

1) The time of flight to a target at 4,000 ft is 30% less than that of a 20mm round, and the projectile drops only 10 ft in the process.

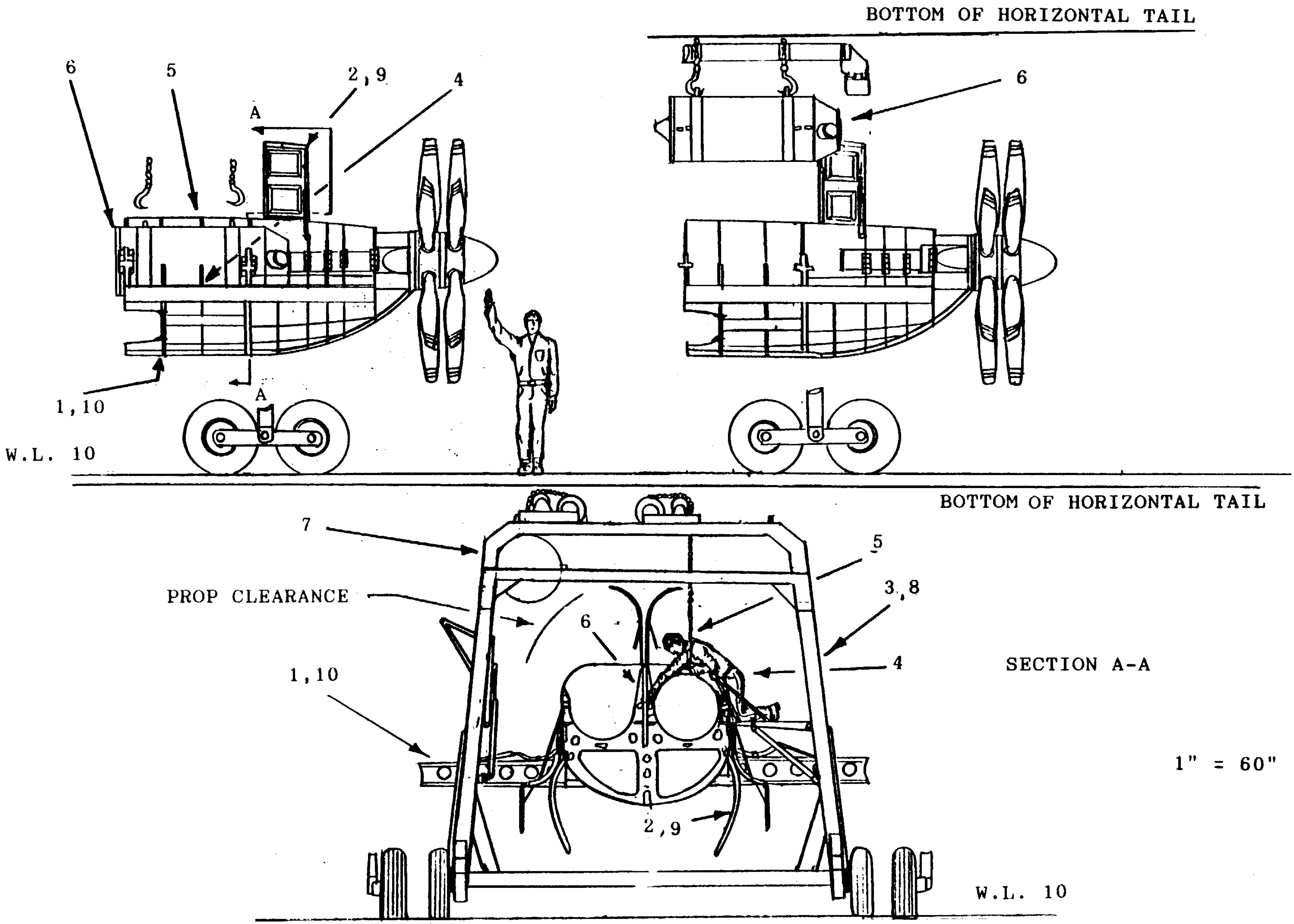


Figure 4.13 Engine removal procedure for the Good and Bad]ad airplanes.

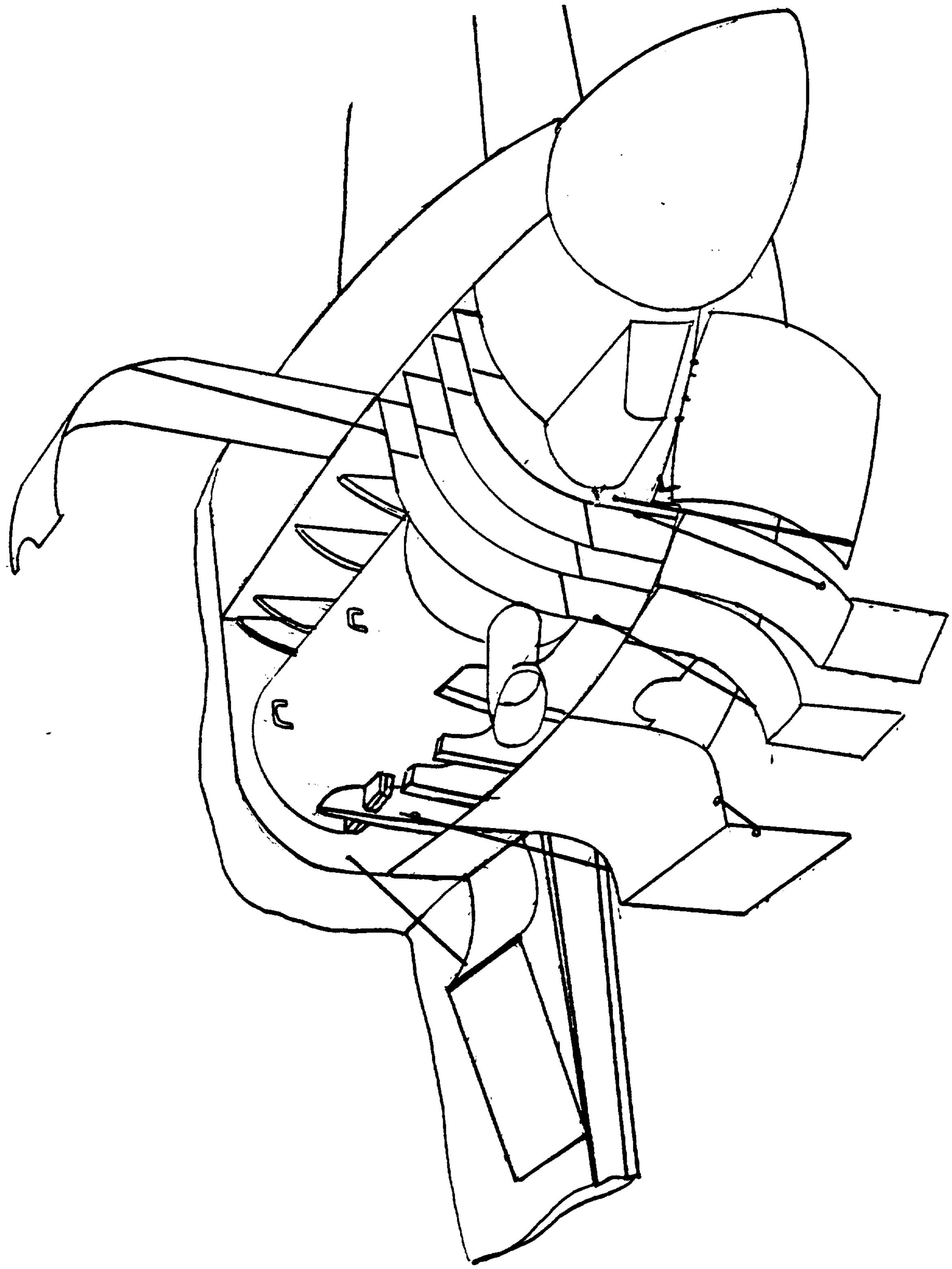


Figure 4.14 Engine access panels for the Good and Bad airplanes.

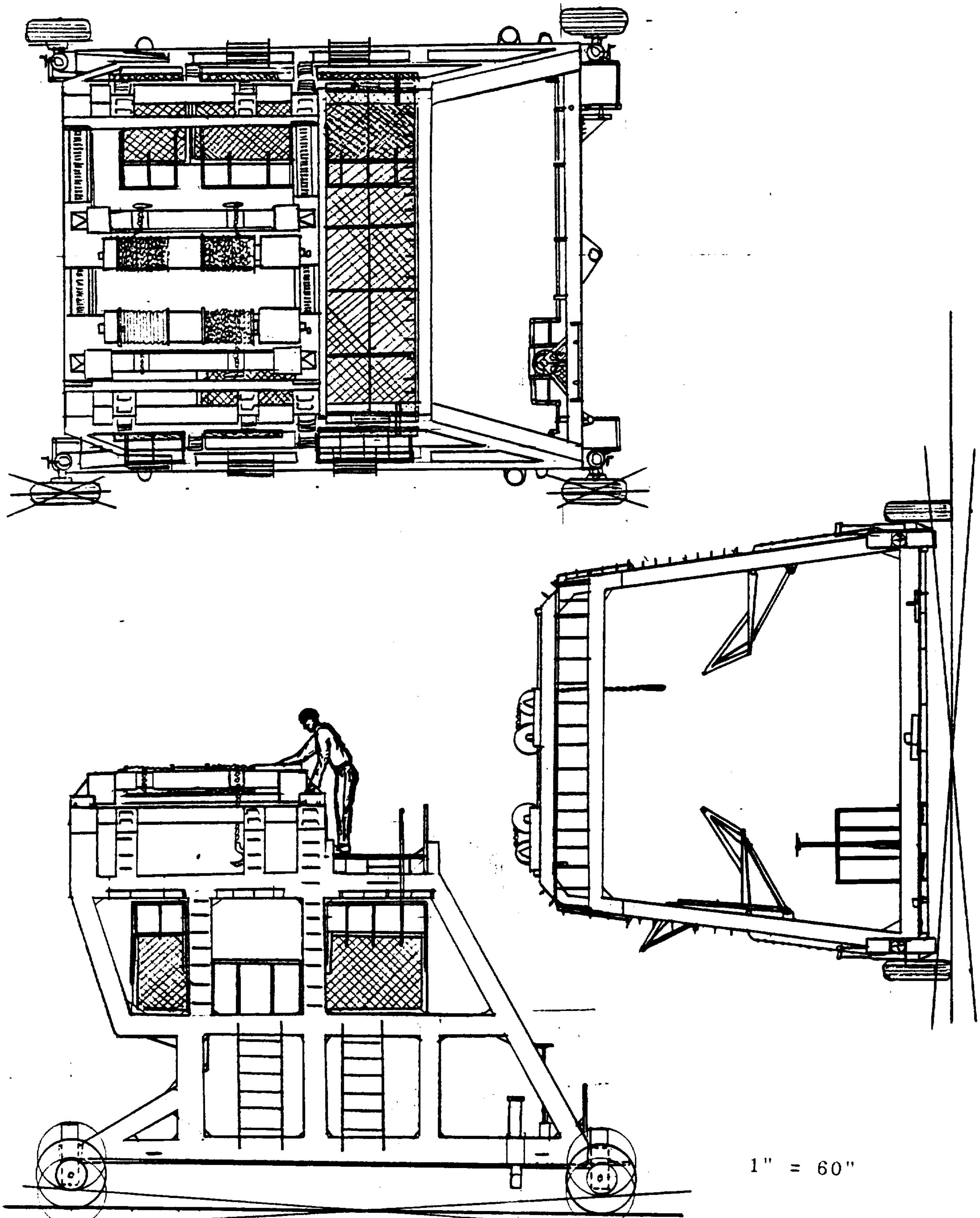


Figure 4.15 Engine maintenance crane for the Good, Bad, and Ugly airplanes.

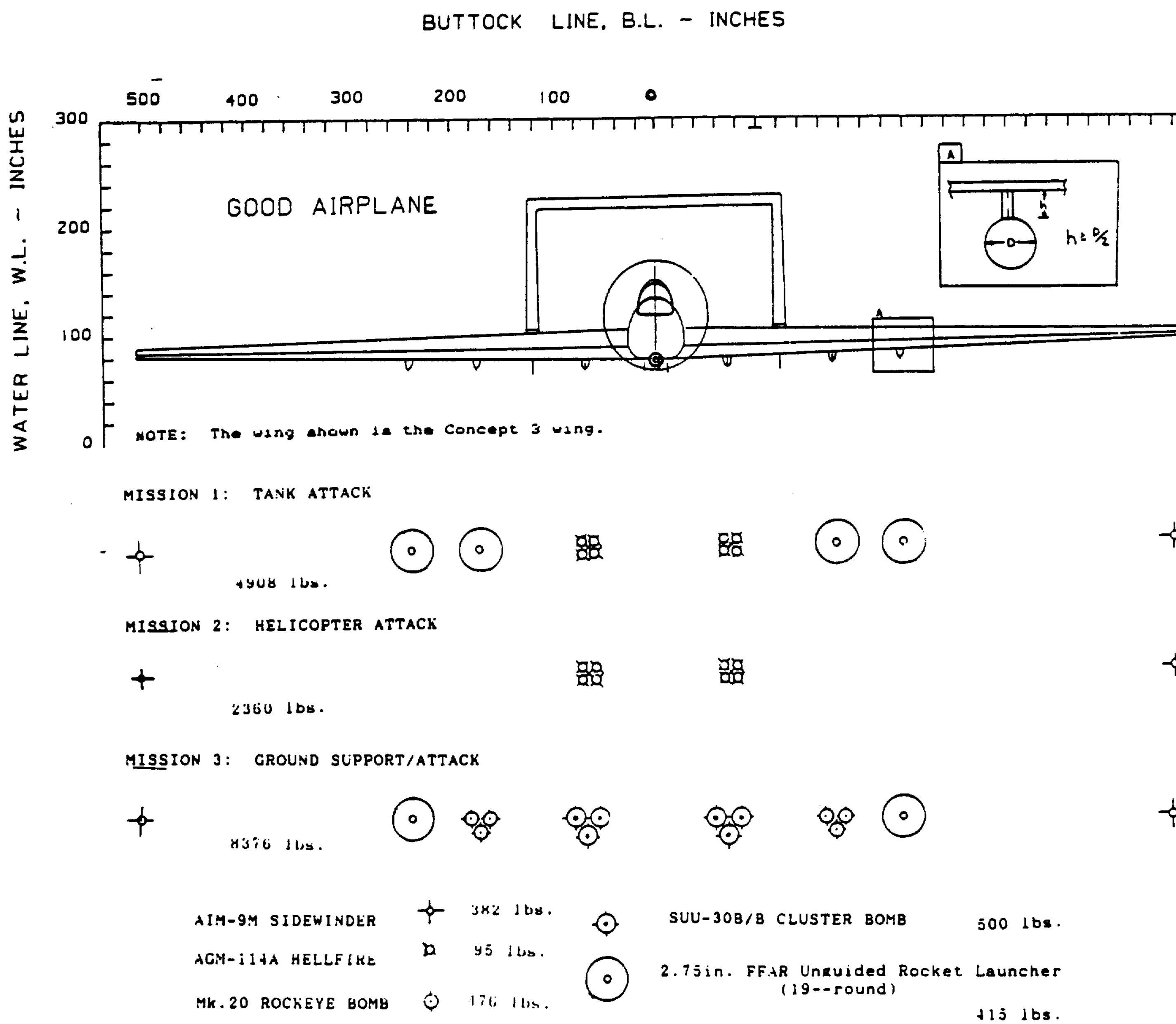


Figure 4.16 Weapon Loading Scenarios for the Good Aircraft.

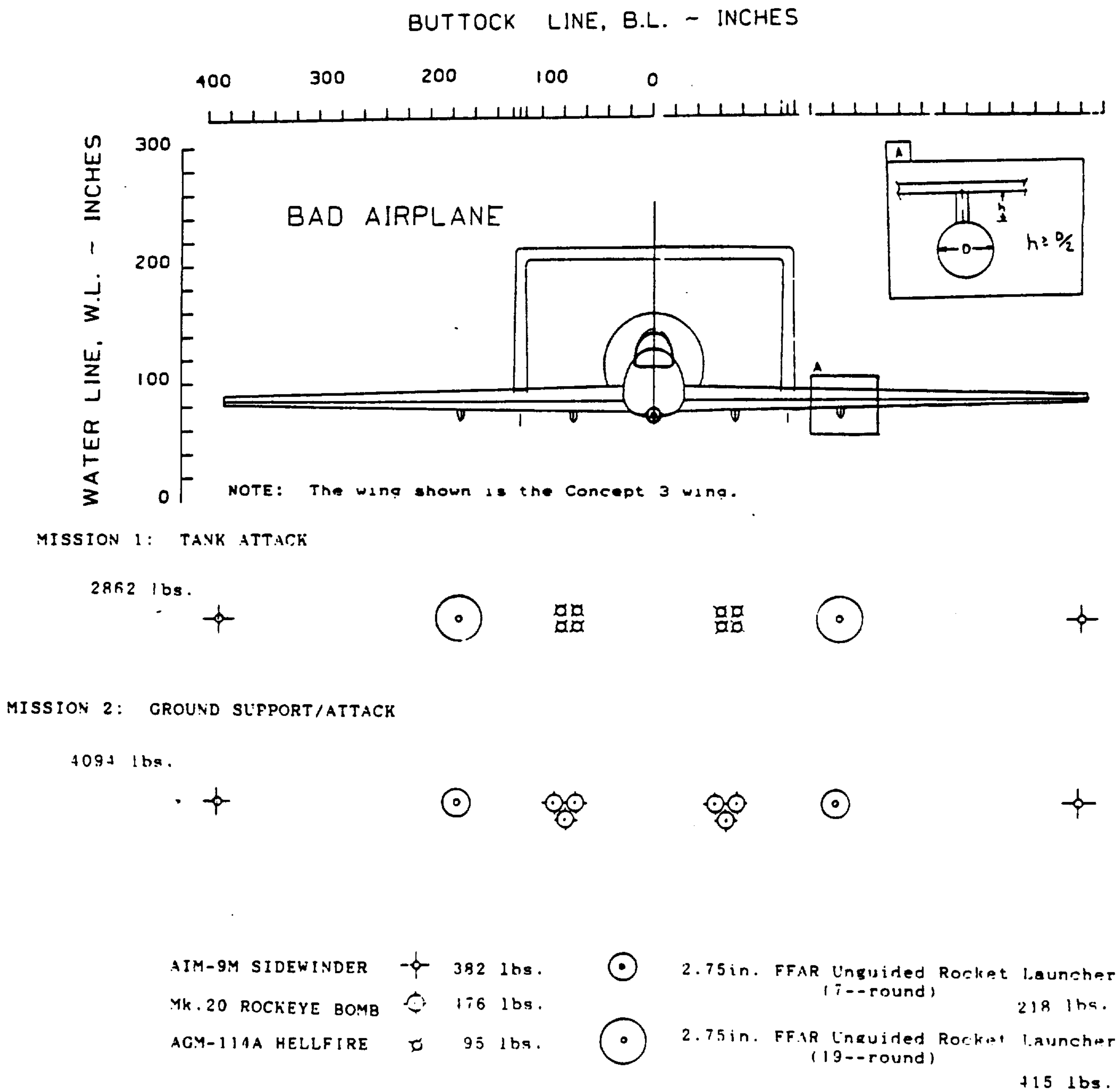
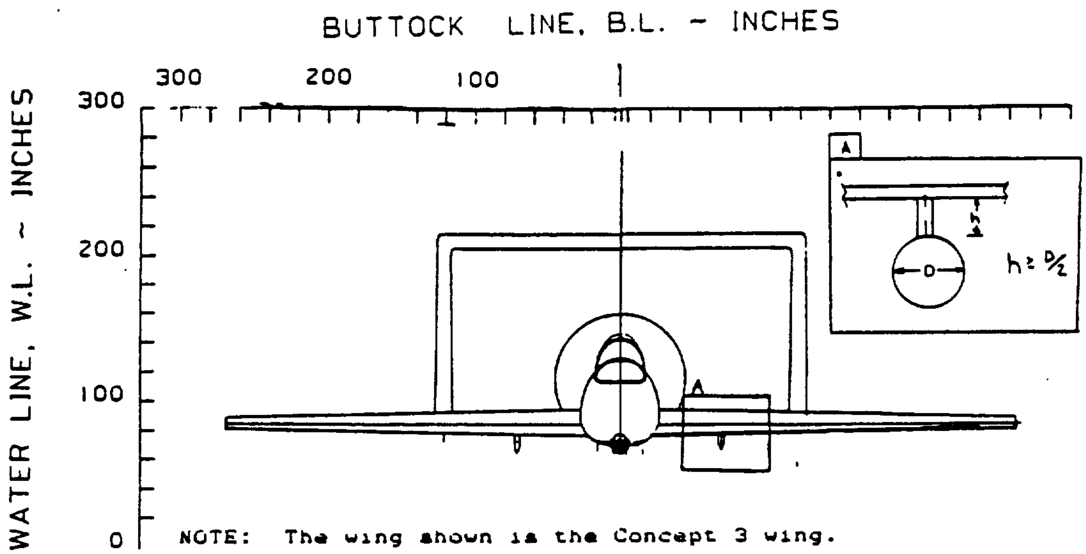


Figure 4.17 Weapon Loading Scenarios for the Bad Aircraft



MISSION 1: TANK ATTACK

1438 lbs.

MISSION 2: GROUND SUPPORT/ATTACK

1668lbs.

2.75in. FFAR Unguided Rocket Launcher (19--round) 415 lbs.

SUU-30B/B CLUSTER BOMB 500 lbs.

Figure 4.18 Weapon Loading Scenarios for the Ugly Aircraft

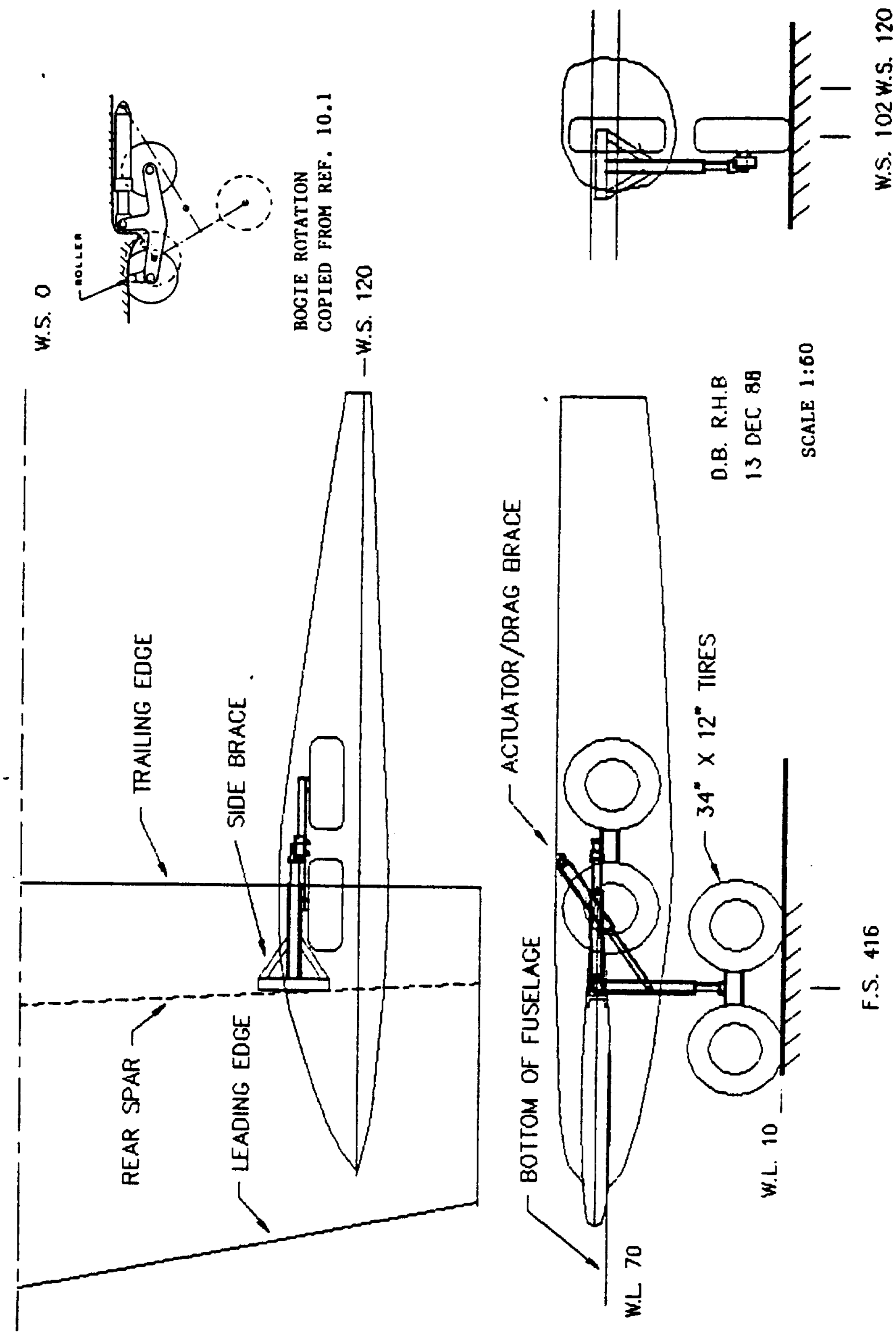


Figure 4.19 Main Gear Installation General Arrangement (Good Aircraft Shown)

2) The ammunition it uses is linkless, preventing jams and reducing the amount of unnecessary weight the airplane must carry.
3) Its accuracy is comparable to the GAU-8/A while serviceability is improved.

The weapons systems are described in greater detail in References 3 and 7.

4.6 Landing Gear

A high degree of commonality has been incorporated into the landing gear for the Good, Bad and Ugly. A detailed discussion of the landing gear design is presented in Reference 7.

A tricycle type landing gear is employed for each airplane. The nose gear is offset from the centerline to allow room for the cannon. It retracts directly aft in all three aircraft, as shown in Figure 4.7. The main gear retract aft beside the booms, as shown in Figure 4.19. Two tires per strut are used in the Good and Bad main gear and a single tire on the Ugly. To avoid using a large fairing to cover the main gear, the tires are arranged in tandem. Due to the large difference in take-off weight and field requirements, the Good aircraft uses different main gear tires than the Bad and Ugly.

The commonality features of the landing gear are:

* The nose gear assembly and tire
* The main landing gear attachment
* The two main gear wheel bogies for the Good and Bad
* Struts and side braces
* Common retraction actuators/drag braces

A summary of the landing gear details is given in Table 4.2.

Table 4.2 Summary of Landing Gear Details

	Good	Bad	Ugly
TIP-OVER CRITERIA			
Longitudinal (deg)	21.8	7.2	14.8
Lateral (deg)			
right	46.5	45.7	49.5
left	39.9	39.4	43.7
TIRES			
Nose			
Tire size	29.1" x 11"	29.1" x 11"	29.1" x 11"
Quantity	1	1	1
Load capability	5,000 lbs	5,000 lbs	5,000 lbs
Actual load	5,275 lbs	2,220 lbs	1,800 lbs
Main			
Tire size	34" x 12"	29.1" x 11"	29.1" x 11"
Quantity	2	2	1
Load capability	10,400 lbs	5,000 lbs	5,000 lbs
Actual load	9,110 lbs	5,270 lbs	2,830 lbs
SHOCK ABSORBERS			
Nose			
Piston diameter	3 in.	3 in.	3 in.
Piston length	6 in.	6 in.	6 in.
Static pressure	707 psi	410 psi	325 psi
Main			
Piston diameter	4 in.	4 in.	4 in.
Piston length	11.5 in.	11.5 in.	11.5 in.
Static pressure	1,470 psi	793 psi	354 psi

5. WEIGHT AND BALANCE

The purpose of this chapter is to discuss the weight, balance and moments of inertia for the Good, Bad and Ugly aircraft. The method used to calculate the weight penalties due to commonality of the three aircraft is also discussed in this chapter. The detailed calculations associated with this chapter are included in Appendix A.

5.1 Weight Penalties due to Commonality

By designing the three CAS aircraft to incorporate a high degree of commonality to reduce the overall life cycle cost, a weight penalty is incurred. This arises from the fact that it is not possible to optimize the structure for lowest weight for all three aircraft.

The following items were considered to be the most influential in determining the weight penalties:

* Wing components
* Nose section
* Landing gear components

1) Wing Components.
The design of the wings for the Good, Bad and Ugly incorporates the wing of the Ugly aircraft as the baseline for all the other wings. To estimate the weight penalties, the following method was used (Reference 9).

1. The total aerodynamic bending moment over the wing of the Good was determined from Vorstab, a program developed at KU (Reference 10). The analysis was done for a cambered wing only, at several angles of attack. Thus, effects of the wing-body intersection were not considered.

2. The most critical point in the flight envelope was determined, which corresponded to the following flight condition:

* Sea level standard conditions, $M = 0.227$
* $n = 9.0$, angle of attack = 18 degrees
* $W = 39,725$ lbs

3. The inertial relief due to the weight of the wing and boom was then determined.

4. The total bending moment over the wing of the Good aircraft was then established. It is shown in Figure A.1 in the appendix. The bending moment was divided into three sections, corresponding to the wingspans of the three aircraft.

5. With these areas, a ratio of the total area under the bending moment curve for each aircraft to the area corresponding

to the Ugly aircraft was obtained. When multiplied by the weight of the wing of the Ugly, a final wing weight was obtained for the Good and the Ugly. The results are listed in Table 5.1

Table 5.1. Commonality Wing Weight Penalty.

	Good	Bad	Ugly
Wing Weight* (lbs)	4,800	2,225	864
Current Wing Weight (lbs)	5,414	2,278	864
Penalty (lbs)	614	53	0

* Weight estimated in Reference 7.

2) Nose Section

To estimate the weight penalty due to the common nose section for the three aircraft, the following method was used:

1. The weights of the fuselages without the nose section were determined from the General Dynamics and USAF method of Reference 11. The two weights that were obtained, were then averaged for each aircraft.

2. These weight were then subtracted from the actual fuselage weights obtained from Reference 7 giving an approximate weight for the nose cones. A 10% weight reduction was factored into the nose cone weights to account for the use of advanced materials in this structure.

3. Since the nose cone for the Good is common to all three, this weight was added to the weights of the fuselages without the nose cones obtained in Step 1, resulting in the new fuselage weights.

The results are given in Table 5.2.

Table 5.2. Fuselage Weight Penalty due to the Common Nose Section

	Good	Bad	Ugly
Fuselage Weight* (lbs)	2,546	1,407	801
Current Fuselage Wt. (lbs)	2,546	1,564	1,143
Penalty (lbs)	0	157	342

*Obtained from Reference 7.

3) Landing Gear

The weight penalties incurred by having a common landing gear were obtained from Reference 7, Chapter 10, and are given in Table 5.3.

Table 5.3. Weight Penalties due to Commonality in Landing Gear

	Good	Bad	Ugly
With Commonality			
Main Gear (lbs)	939	793	705
Nose Gear (lbs)	235	235	235
No Commonality			
Main Gear (lbs)	939	500	320
Nose Gear (lbs)	235	200	80
Penalty (M.G./N.G.) (lbs)	0/0	293/35	385/155

Table 5.4 summarizes the overall weight penalties associated with the various components that have commonality.

Table 5.4. Weight Penalties due to Commonality

Component	Good	Bad	Ugly
Wing	614	53	0
Fuselage	0	157	342
Landing Gear	0	328	540
Horizontal Tail*	0	80	98
Vertical Tail*	0	34	70
TOTAL	614	652	1,050

*Obtained from Reference 7.

5.2 Balance

The methods of Reference 12 were used in developing the weight and balance statements for the three aircraft. The labeling method for the stores is that Store #1 corresponds to the innermost store. To obtain the balance statement as shown in Tables 5.5-5.7, several factors had to be taken into consideration:

A) Component center of gravity locations (Figs. 5.1-5.3)
B) C.G. travel
C) Static margin at the aft C.G.

The C.G. excursion diagrams shown in Figures 5.4-5.6 were used to determine the aft C.G. locations as well as the overall C.G. travel for the three aircraft. The C.G. travels were:

Good	18 in	12.7% MGC
Bad	18 in	15.4% MGC
Ugly	11 in	11.6% MGC

Table 5.5 Component Weight and Balance for the Good Airplane

COMPONENT	Weight (lbs)	X-CG (in)	Y-CG (in)	Z-CG (in)
Wing				
Section 1	432	436	-336	86
Section 2	707	418	-174	86
Section 3	3,136	406	0	86
Section 4	707	418	174	86
Section 5	432	436	336	86
Horizontal Tail	416	782	0	210
Vertical Tail	286	767	0	155
Boom	244	500	0	86
Fuselage	2,546	278	0	95
Nacelle	200	460	0	95
Landing Gear - Nose	235	159	3	40
- Main	939	430	0	40
STRUCTURE TOTAL	10,280	410	0	90
Left Engine	1,250	467	-24	100
Right Engine	1,250	467	24	100
Gearbox	1,500	537	0	115
Air Induction	700	412	0	115
Propeller	600	582	0	115
Fuel System	564	429	0	86
Fuel Dump	26	469	0	86
Engine Starting System	46	457	0	100
Engine Controls	92	457	0	100
Propeller Controls	287	582	0	115
Oil System	175	467	0	100
POWERPLANT TOTAL	6,490	489	0	106
Flight Controls	816	419	0	95
Hydraulic and Pneumatic	324	380	0	90
Instrumentation	461	114	0	100
Electrical System	505	380	0	100
A/C, Pressurization	161	380	0	95
Oxygen System	0	200	0	95
Furnishings	165	160	0	105
Auxiliary Gear	203	360	0	100
Paint	121	360	0	100
30 mm Gatling Gun	1,200	195	0	73
FIXED EQUIPMENT	3,956	290	0	90

Table 5.5 cont.

EMPTY WEIGHT TOTALS	20,726	412	0	95
Trapped Fuel and Oil	198	421	0	86
Crew	225	146	0	115
OPERATING EMPTY TOTAL	21,149	409	0	95
Fuel	10,200	414	0	86
Ammunition	936	216	0	105
Stores #1	3,186	358	0	45
Stores #2	3,042	374	0	45
Stores #3	830	390	0	45
Stores #4	382	436	0	45
TAKE-OFF WEIGHT	39,725	399	0	84

Table 5.6 Component Weight and Balance for the Bad Airplane

COMPONENT	Weight (lbs)	X-CG (in)	Y-CG (in)	Z-CG (in)
Wing				
Section 1	432	436	-336	86
Section 2	707	418	-174	86
Section 4	707	418	174	86
Section 5	432	436	336	86
Horizontal Tail	416	782	0	210
Vertical Tail	286	767	0	155
Boom	244	500	0	86
Fuselage	1,564	278	0	95
Nacelle	200	305	0	95
Landing Gear - Nose	200	209	3	40
- Main	500	430	0	40
STRUCTURE TOTAL	5,688	420	0	96
Left Engine	600	462	-24	100
Right Engine	600	462	24	100
Gearbox	600	522	0	115
Air Induction	896	435	0	115
Propeller	430	552	0	115
Fuel System	361	401	0	86
Fuel Dump	20	411	0	86
Engine Starting System	16	442	0	100
Engine Controls	82	442	0	100
Propeller Controls	45	550	0	115
Oil System	84	462	0	100
POWERPLANT TOTAL	3,734	470	0	106
Flight Controls	551	390	0	95
Hydraulic and Pneumatic	173	380	0	90
Instrumentation	289	164	0	100
Electrical System	376	380	0	100
A/C, Pressurization	130	380	0	95
Oxygen System	0	225	0	95
Furnishings	130	225	0	105
Auxiliary Gear	121	380	0	100
Paint	65	380	0	100
30 mm Gatling Gun	1,200	245	0	73
FIXED EQUIPMENT	3,035	301	0	88
EMPTY WEIGHT TOTALS	12,457	406	0	97

Table 5.6 cont.

Trapped Fuel and Oil	109	390	0	86
Crew	225	196	0	115
OPERATING EMPTY TOTAL	12,791	402	0	97
Fuel	5,030	395	0	86
Ammunition	608	266	0	105
Stores #1	3,042	338	0	45
Stores #2	436	364	0	45
Stores #3	382	406	0	45
TAKE-OFF WEIGHT	22,289	387	0	86

Table 5.7 Component Weight and Balance for the Ugly Airplane

COMPONENT	Weight (lbs)	X-CG (in)	Y-CG (in)	Z-CG (in)
Wing				
Section 1	432	381	-336	86
Section 5	432	381	336	86
Horizontal Tail	286	639	0	210
Vertical Tail	286	620	0	155
Boom	166	480	0	86
Fuselage	1,143	277	0	95
Nacelle	75	408	0	107
Landing Gear - Nose	80	224	3	40
- Main	320	415	0	40
STRUCTURE TOTAL	3,220	393	0	101
Engine	500	430	-24	107
Gearbox	300	482	0	112
Air Induction	252	408	0	112
Propeller	300	501	0	112
Fuel System	137	376	0	86
Fuel Dump	11	401	0	86
Engine Starting System	4	420	0	107
Engine Controls	48	420	0	107
Propeller Controls	28	501	0	112
Oil System	35	430	0	100
POWERPLANT TOTAL	1,615	446	0	108
Flight Controls	357	386	0	95
Hydraulic and Pneumatic	86	385	0	90
Instrumentation	178	179	0	100
Electrical System	254	385	0	100
A/C, Pressurization	111	385	0	95
Oxygen System	0	272	0	95
Furnishings	116	230	0	105
Auxiliary Gear	68	385	0	100
Paint	32	390	0	100
30 mm Gatling Gun	1,200	260	0	73
FIXED EQUIPMENT	2,402	300	0	85
EMPTY WEIGHT TOTALS	7,237	374	0	97
Trapped Fuel and Oil	55	382	0	86
Crew	225	211	0	115

Table 5.7 cont.

OPERATING EMPTY TOTAL	7,517	369	0	98
Fuel	1,750	376	0	86
Ammunition	608	281	0	105
Stores #1	1,060	338	0	45
TAKE-OFF WEIGHT	10,935	362	0	91

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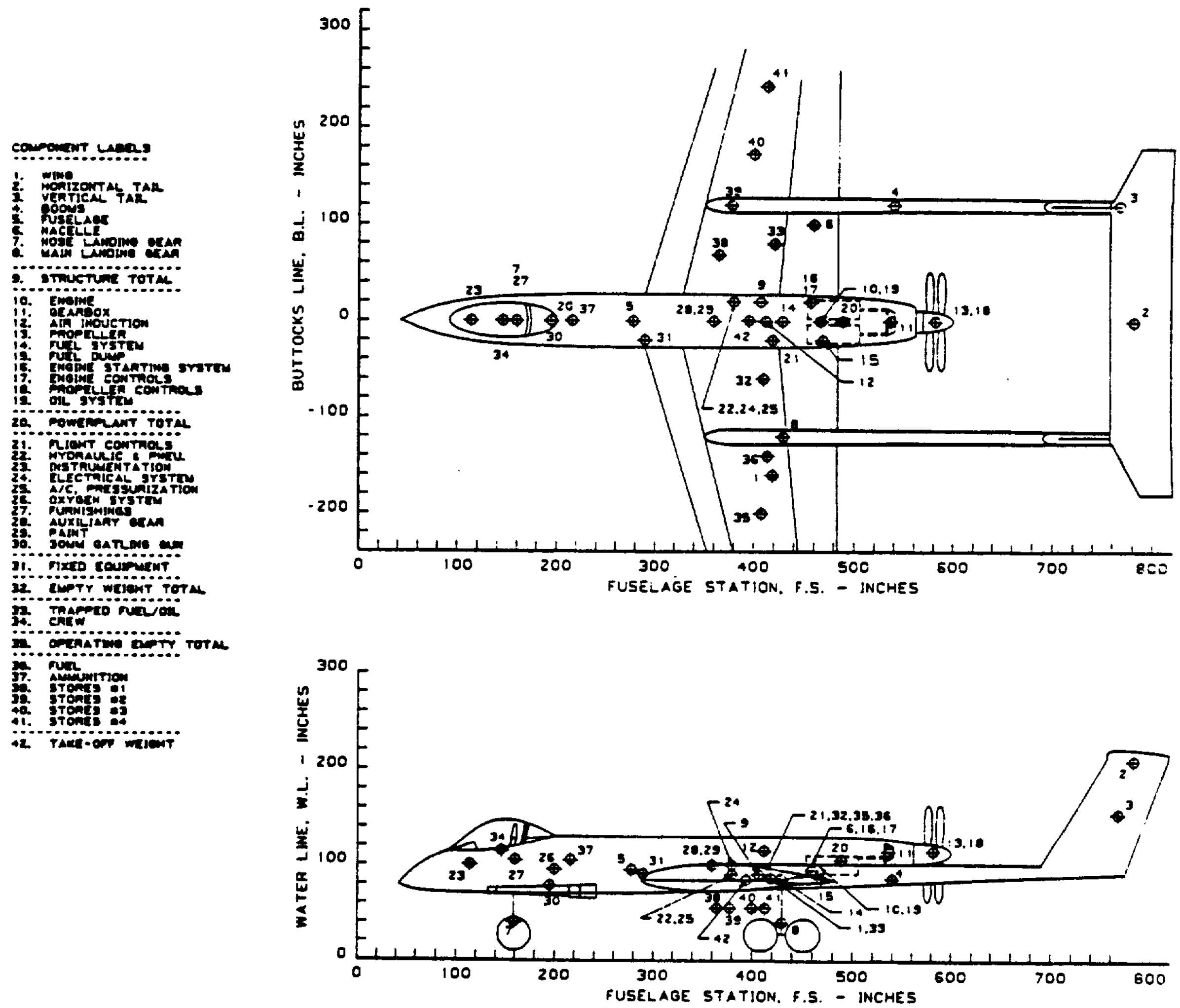

Figure 5.1 Component C.G. Locations for the Good Aircraft

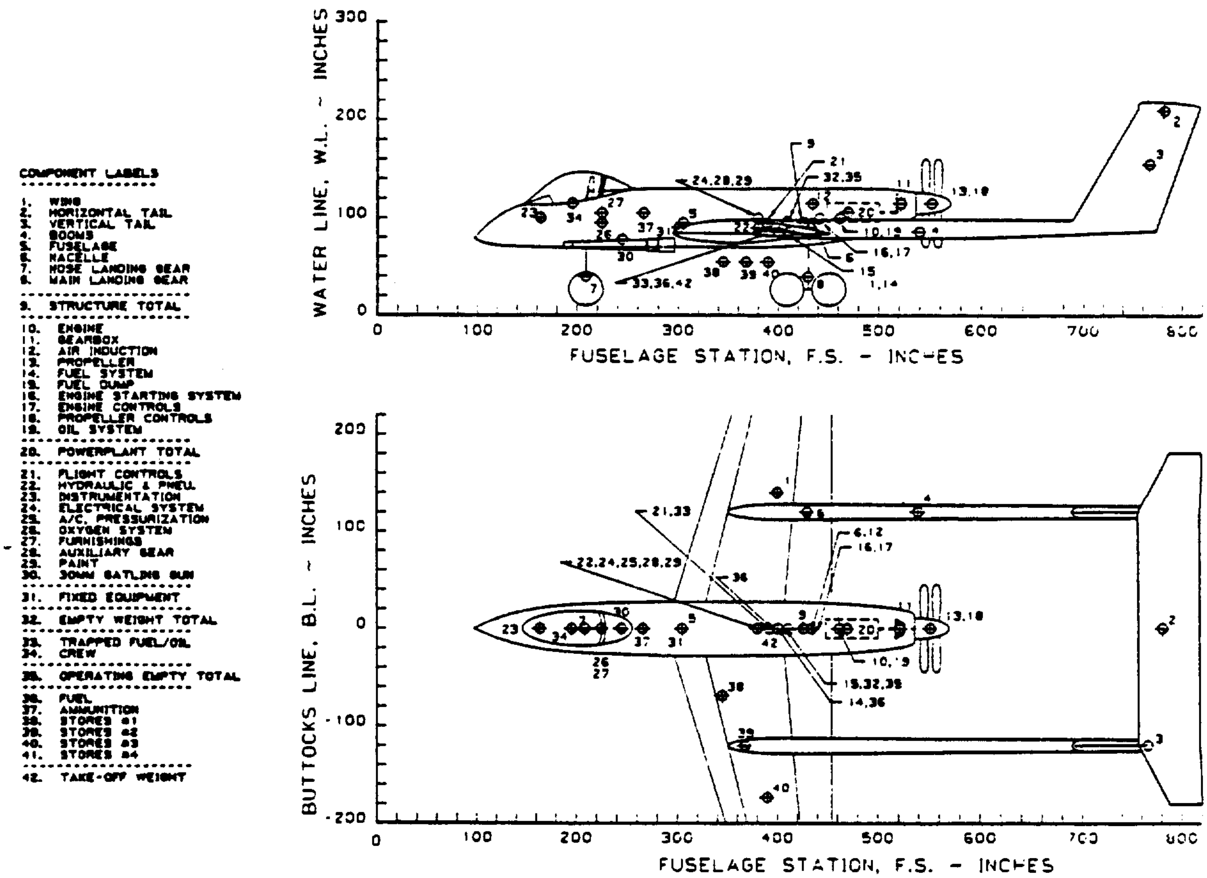

Figure 5.2 Component C.G. Locations for the Bad Aircraft

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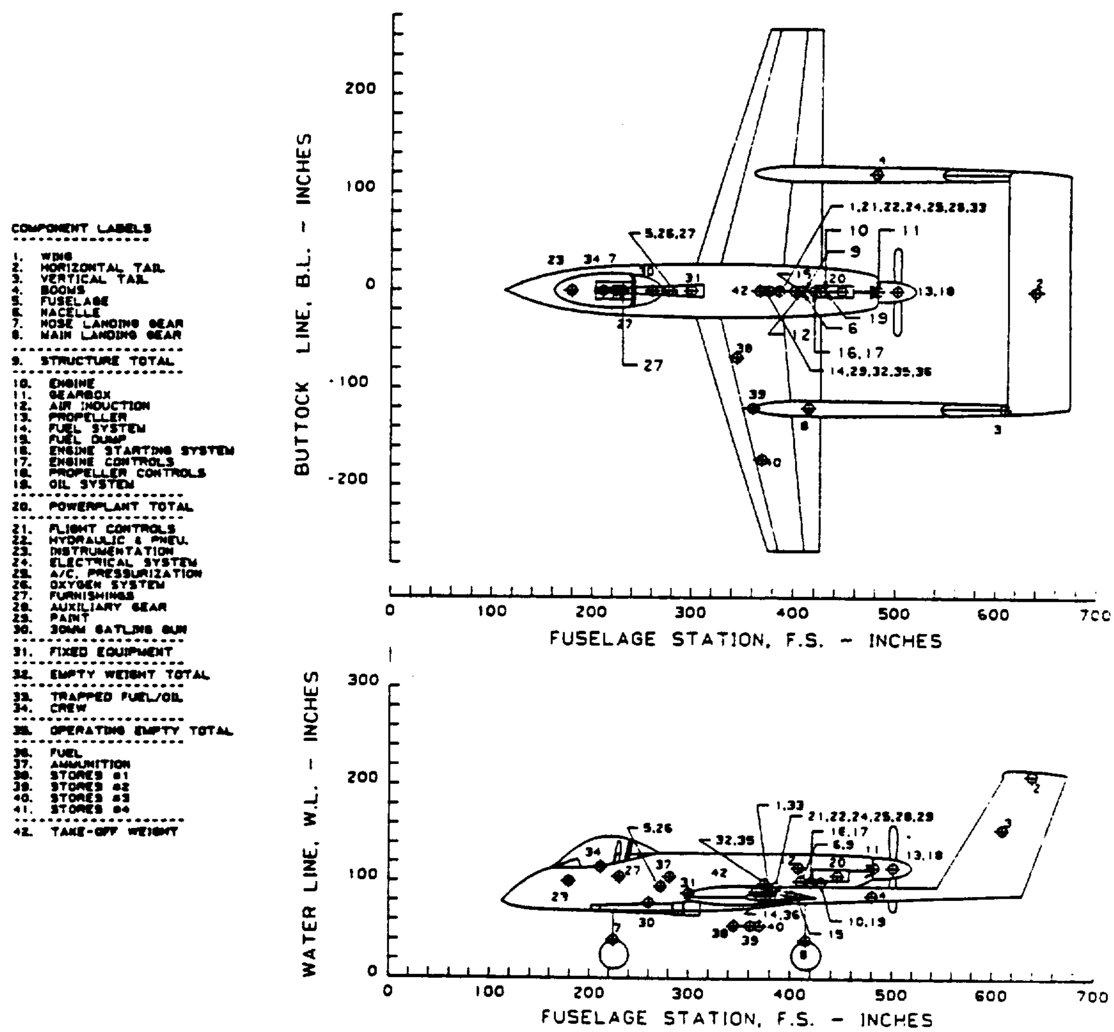

Figure 5.3 Component C.G. Locations for the Ugly Aircraft

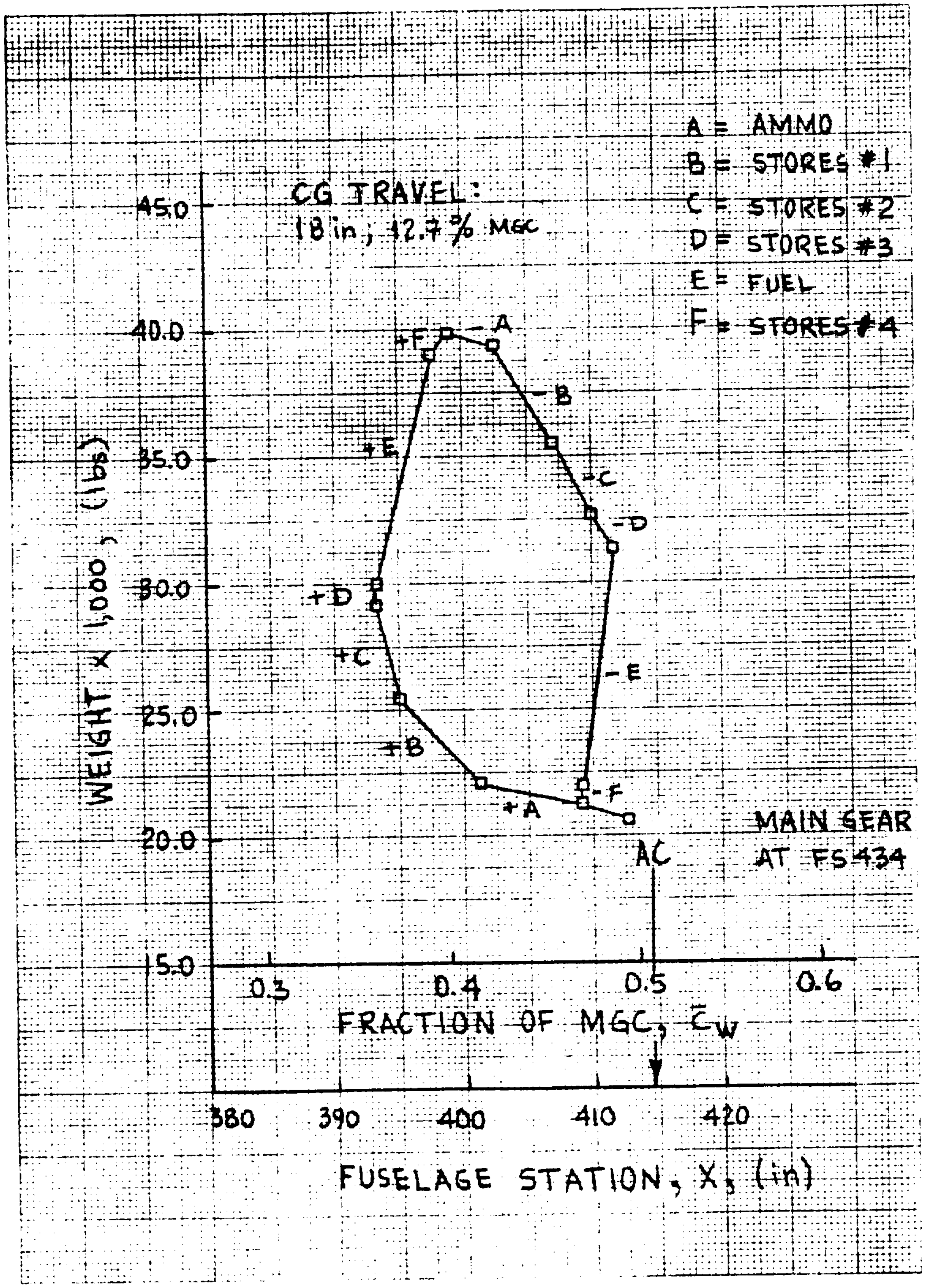

Figure 5.4 C.G. Excursion Diagram for the Good Airplane

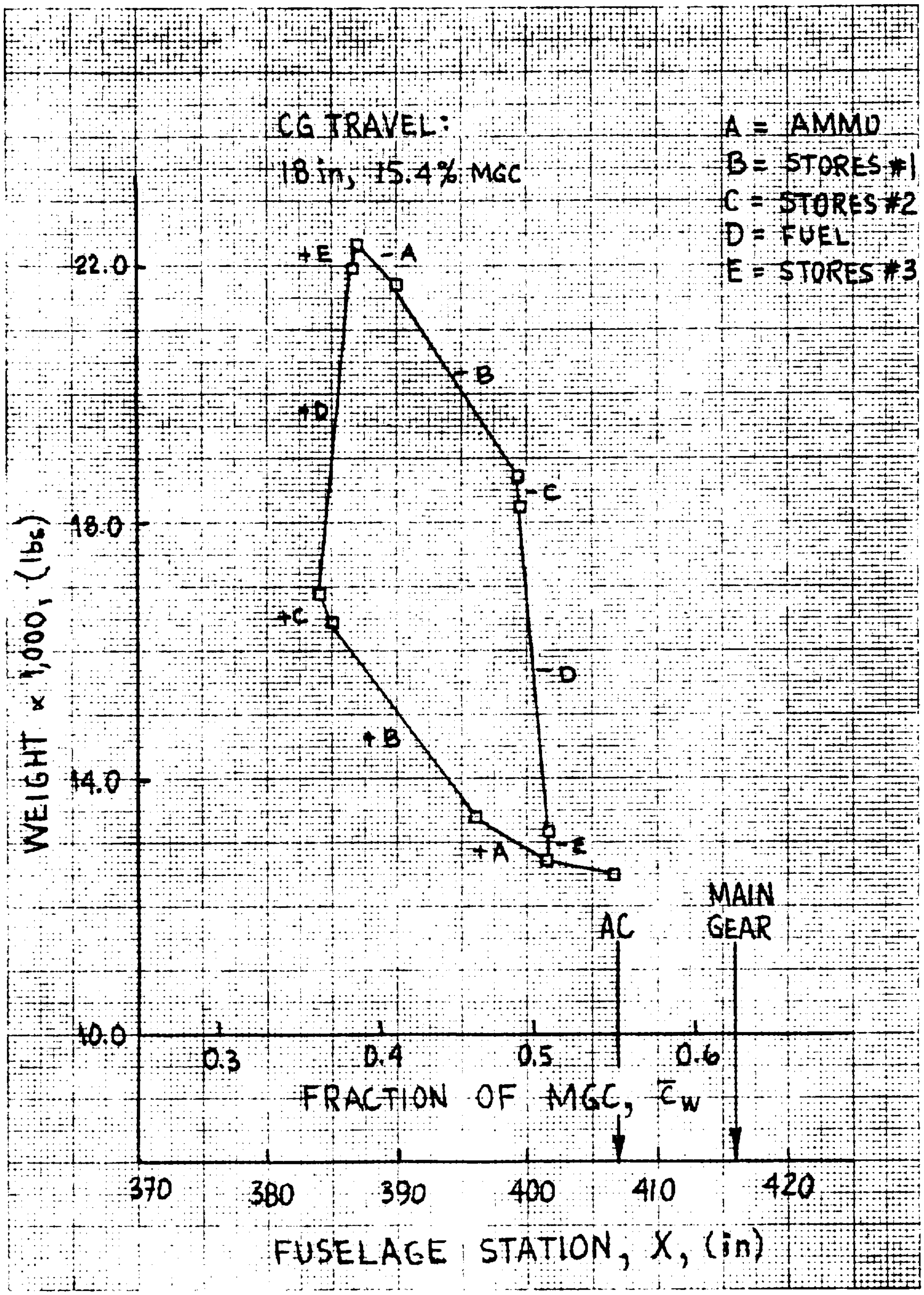

Figure 5.5 C.G. Excursion Diagram for the Bad Airplane

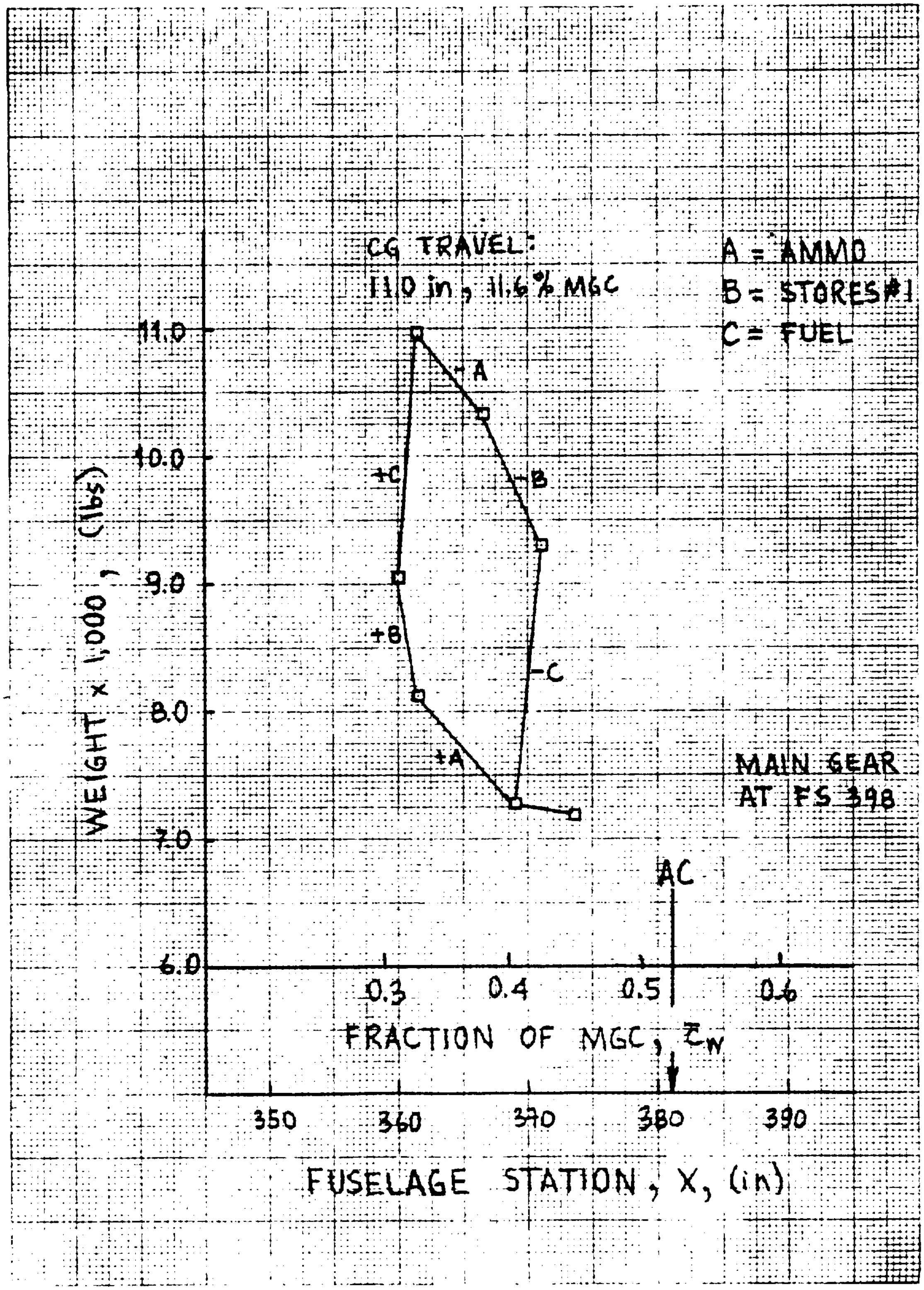

Figure 5.6 C.G. Excursion Diagram for the Ugly Airplane

These figures are comparable to the accepted range of C.G. travel indicated in Reference 12, which are 15 inches or 20% of MGC.

5.3 Moment of Inertia

The moment of inertia values for the three aircraft are shown in Table 5.5. These values are compared to typical moment of inertia trends for various aircraft in Figures 5.7-5.9.

Table 5.5 Moments of Inertia for the Good, Bad and Ugly

	Ixx	Iyy	Izz	Ixz
Good				
Oper. Weight Empty	38,883	80,854	113,300	6,420
Take-Off Weight	42,279	94,773	102,181	7,806
Bad				
Oper. Weight Empty	34,438	56,030	85,182	6,711
Take-Off Weight	36,310	62,760	82,379	8,170
Ugly				
Oper. Weight Empty	23,688	24,260	44,419	3,507
Take-Off Weight	24,455	26,324	42,574	3,646

*Note: All moment of inertia values in slug ft^2

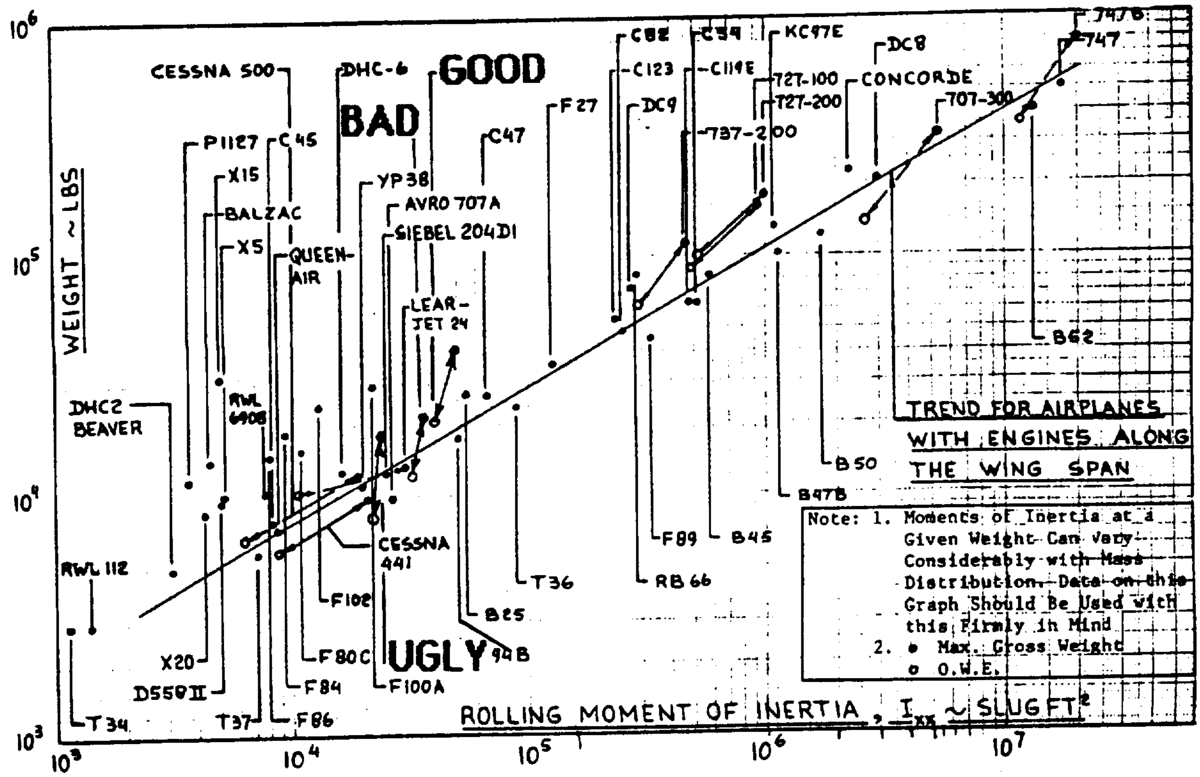

Figure 5.7 Rolling Moment of Inertia Trend for Various Airplanes

Copied from Reference 13

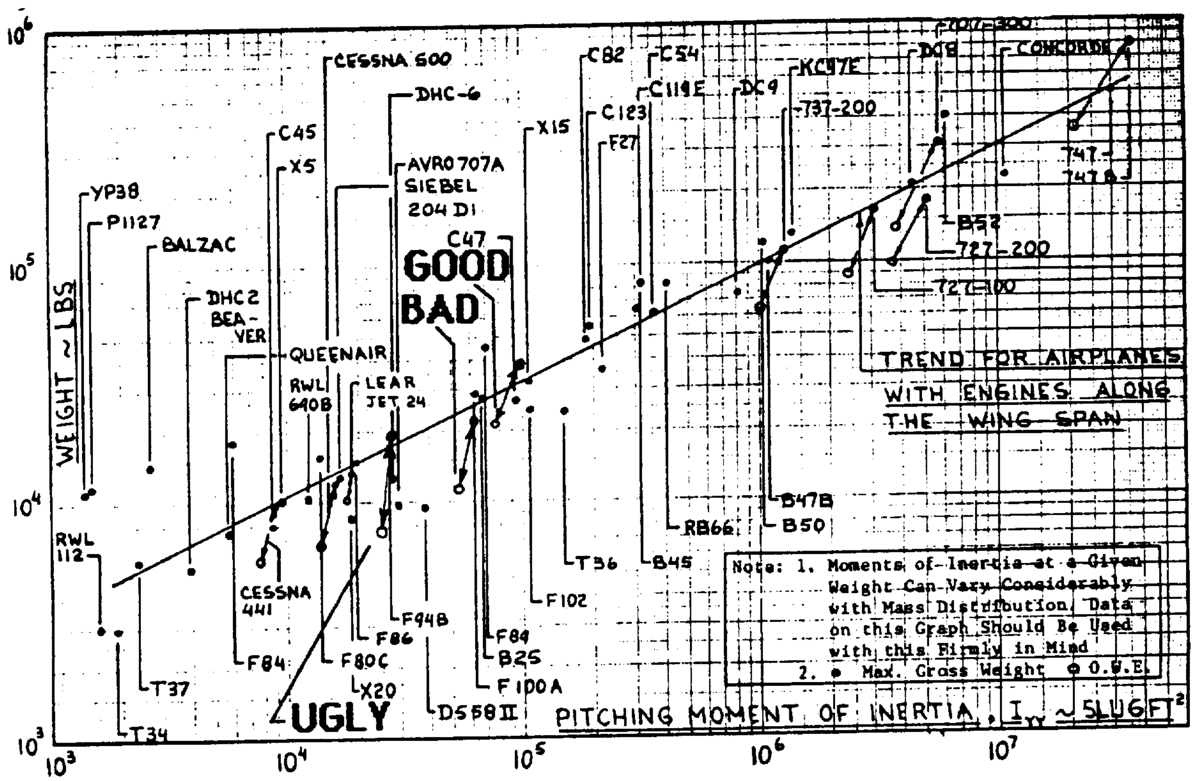

Figure 5.8 Pitching Moment of Inertia Trend for Various Airplanes

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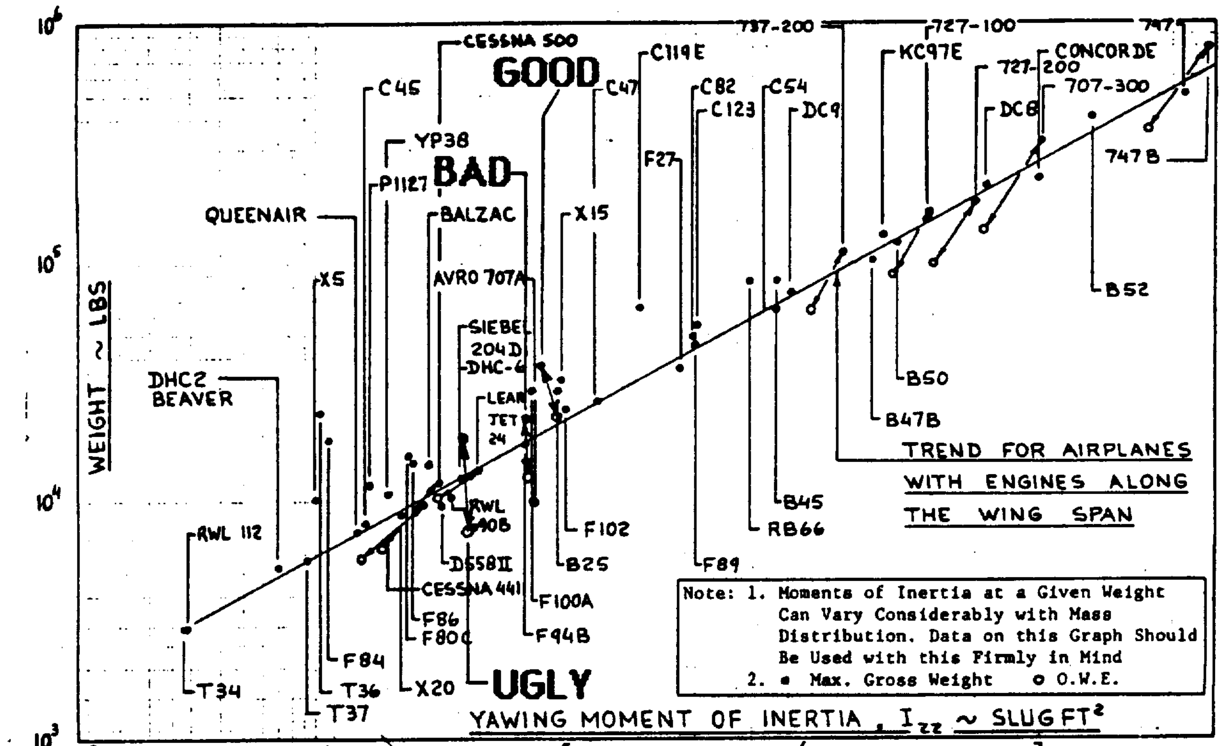

Figure 5.9 Yawing Moment of Inertia Trend for Various Airplanes

Copied from Reference 13.

6. PERFORMANCE

The purpose of this chapter is to discuss the performance requirements of the Good, Bad and Ugly aircraft and report if these requirements are met. The requirements are:

* Maximum speed
* Combat radius
* Endurance
* Take-off/landing groundruns
* Combat Ceiling
* Maximum load factor
* Military climb requirements

The detailed calculations pertinent to this chapter are included in Appendix B.

6.1 Maximum Speed

The mission specifications for the three aircraft were as follows:

Good: 350 kts, SLS, fully loaded
Bad: 350 kts, SLS, clean
Ugly: 350 kts, SLS, clean

The maximum speeds for the three aircraft were determined from the performance diagrams of each aircraft (Figures 6.1-6.3) and are listed in Table 6.1.

6.2 Combat Ceiling

The mission specifications state that the ceiling requirements for the Good, Bad and Ugly are:

Good: 15,000 ft
Bad: no requirement
Ugly: no requirement

For military aircraft, the combat ceiling is defined as the altitude where the rate of climb is 500 fpm at maximum power. The input data for the calculations are:

* Aircraft weight
* Propeller efficiency of 0.82
* Wing loading
* Air density ratio

The results are listed in Table 6.1.

6.3 Combat Radius

The combat radius determined in the mission specifications for each of the three aircraft are:

Good: 400 nm

Bad: 120 nm
Ugly: 100 nm

The Breguet range equation was applied for each segment of the mission. The individual segments were then added up to obtain an overall combat radius. The input data for each segment of the mission for the range equation are:

* Propeller efficiency
* Specific fuel consumption
* Lift-to-drag ratio
* Ratio of initial to final weights

6.4 Maneuvering Load Factor

The maneuvering requirements listed in the mission specification are:

Good: 5 g's sustained, 150 kts SLS, fully loaded
Bad: 5 g's sustained, 125 kts SLS, fully loaded
Ugly: 5 g's sustained, 125 kts SLS, fully loaded

The method listed in Reference 14, Chapter 5 was used to determine the maneuvering load factors for the aircraft. The input data was:

* Weight, wing area, aspect ratio
* Dynamic pressure
* Maximum trimmed lift coefficient
* Drag polars

The results of the calculations are listed in Table 6.1.

6.5 Endurance

The endurance requirements stated in the mission specifications for the Good, Bad and Ugly are:

Good: 1 hour at 5,000 ft
Bad: 4 hours at 5,000 ft
Ugly: 2 hours at 5,000 ft

The input data are:

* Propeller efficiency
* Average specific fuel consumption
* Beginning and final weights
* Lift coefficient
* Drag polars, density and wing area

The results are presented in Table 6.1.

6.6 Military Climb Requirements

The following military climb requirements must be met by the Good, Bad and Ugly aircraft:

1) RC > 500 fpm with one engine out, SL 95 F, and maximum take-off weight
2) Climb gradient (CGR) > 0.005 at take-off speed, Vto = 1.1 Vstall(to).

The results are listed in Table 6.1.

6.7 Take-off and Landing Groundrun

The Good, Bad and Ugly are required to have the following groundruns:

Good:	2,000 ft, steel planking
Bad:	1,200 ft, soft field
Ugly:	1,000 ft, soft field

The method of Reference 14 was used to estimate the take-off and landing groundruns. The results of the calculations are listed in Table 6.1.

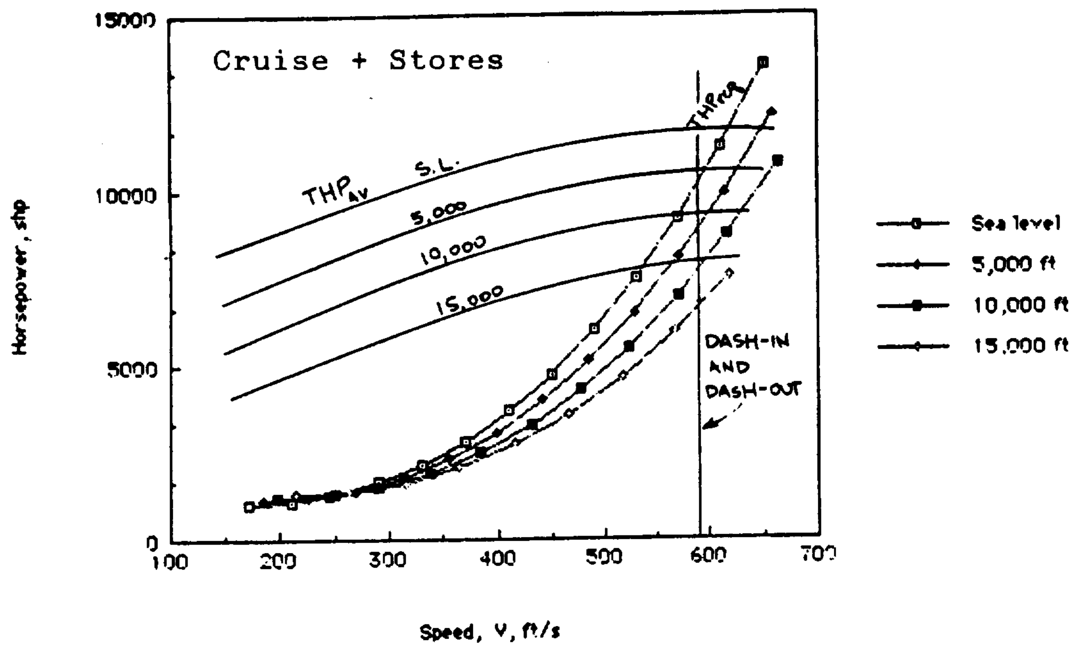

Figure 6.1 Performance Diagram for the Good Airplane

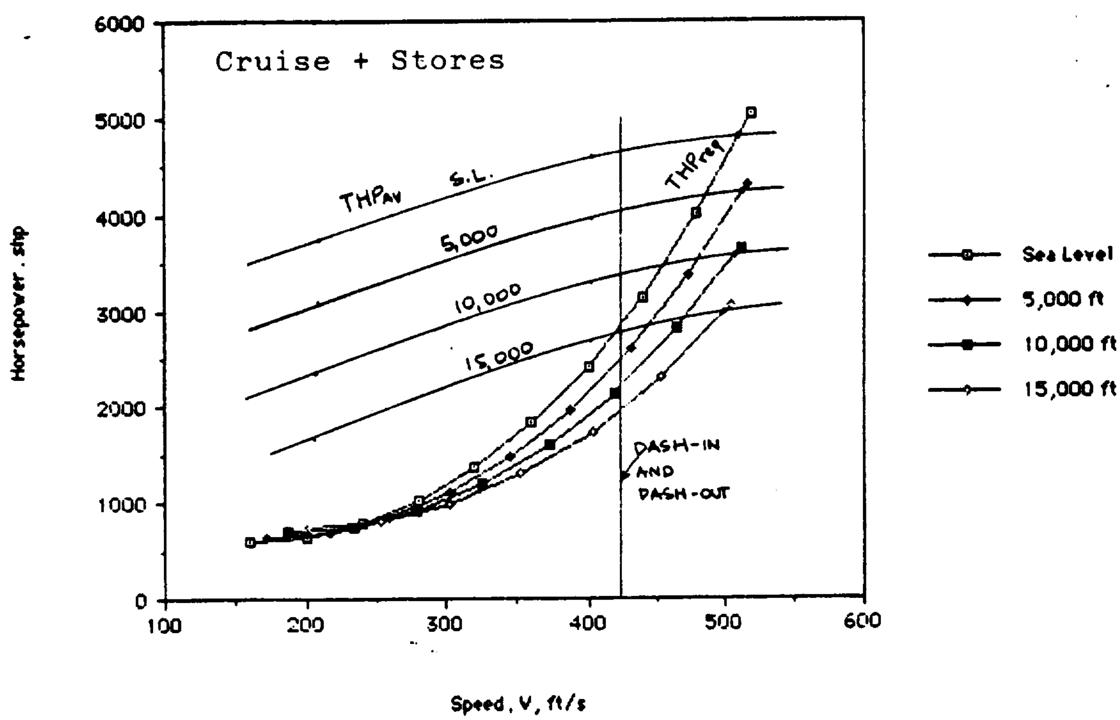

Figure 6.2 Performance Diagram for the Bad Airplane

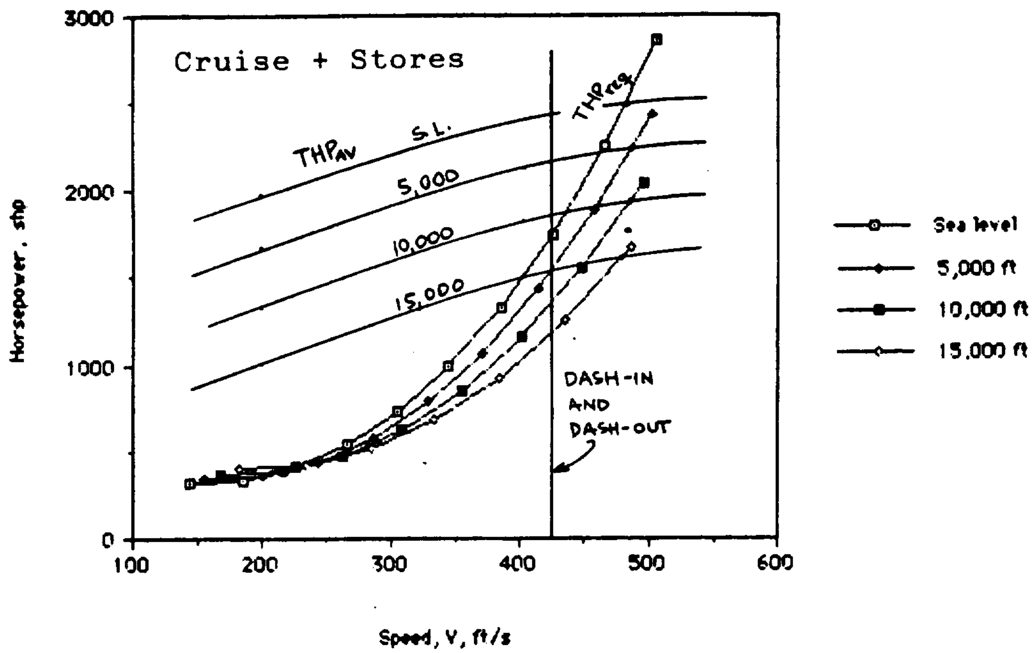

Figure 6.3 Performance Diagram for the Ugly Airplane

Table 6.1 Peformance Characteristics for the Good, Bad, and Ugly Aircraft

	The Good		The Bad		The Ugly	
	REQUIRED	ACTUAL	REQUIRED	ACTUAL	REQUIRED	ACTUAL
Maximum Speed, (kts)						
Sea level, fully loaded	350	364	250	299	250	281
Stalling Speed, (kts)						
Sea level, Wto + stores		100		93.6		86.1
Take-off, Wto + stores		96.9		90.2		77.6
Landing, 90% Wto		88.9		75.5		62.8
Maneuvering						
150 kts, SL, fully loaded	5 g's	5.2 g's	5 g's	4.99 g's	5 g's	5.2 g's
Take-off Groundrun, (ft)	2,000	1,810	1,200	1,120	1,000	710
Landing Groundrun, (ft)	2,000	1,130	1,200	816	1,000	560
Endurance @ 5,000 ft, (hrs)	1.0	1.33	4.0	5.16	2.0	3.37
Combat Ceiling, (ft)	15,000	34,300		31,000		32,500
Combat Radius, (nm)	400	560	120	168	100	157
Military Climb Requirements						
Take-off min. RC, OEI, (fpm)	500	726	500	645	500	759
Take-off CGR, (rad)	0.005	0.067	0.005	0.064	0.005	0.108

7. STABILITY AND CONTROL ANALYSIS

The purpose of this chapter is to present the aerodynamic force and moment coefficients, the static (steady state) stability criteria, and the dynamic stability and response characteristics for the good airplane. These stability and control characteristics are analyzed at eight flight conditions.

The airplane is considered to be a rigid body. The computational work was performed on a spreadsheet. The stability and control derivatives are calculated. The numerical values for the calculated derivatives are presented in the Tables of Appendix C. It is advised to read carefully the instructions of Appendix C on 'HOW TO READ THE SPREADSHEET', so that necessary information can be found quickly in the tables.

7.1 Basic Aerodynamic Parameters

The purpose of this section is to discuss the basic aerodynamic parameters of the Good airplane which are needed in the development of aerodynamic forces and moments.

7.1.1 Airfoil Parameters

The airfoil used for the wing is the NACA 642A215 taken from Reference 7. The horizontal and vertical tails use the NACA 64_1-012 airfoil section. The airfoil aerodynamic characteristics are found in Reference 15, p. 217, Tables 8.1b & c. They are presented in Table C.1 of Appendix C.

7.1.2 Planform Parameters

The wing, horizontal tail, and vertical tails geometric characteristics are shown in Chapter 4. The geometric dimensions of the planforms are tabulated in Table C.1 of Appendix C.

7.1.3 Airplane Lift Curve Slope

The subsonic lift curve slopes for the wing, horizontal tail, and vertical tail are calculated and corrected with the aspect ratio correction factor K of Reference 13, Fig. 3.12, p.72. The airplane lift curve slope variation with Mach number is tabulated in Table C.3, Appendix C and is shown in Figure 7.6.

7.1.4 Downwash In The Wing Wake

The subsonic downwash behind the wing, at the horizontal tail, is calculated using the method of Reference 16, Eqn.8.45, p.272. It is shown as a function of Mach number in Figure 7.1.

7.1.5 Airplane Aerodynamic Center Location

The airplane aerodynamic center location is calculated using the method of Reference 16, Chapter 8. The fuselage is sectioned into 13 sections as indicated by the method and the fuselage contribution to aerodynamic center shift is computed. Also, one tailboom is sectioned into 13 sections; sections 1 through 5 being zero in delta xi and wf(xi). The tailboom contribution to aerodynamic center shift is computed. The computed contribution for one tailboom is multiplied by 2. This is added to the fuselage contribution.

The numerical values for the fuselage and tailbooms contribution to the aerodynamic center location shift are tabulated in Table C.3 of Appendix C. Figure 7.2 displays the airplane aerodynamic center location shift variation with Mach number. In the same figure, the wing-fuselage aerodynamic center location shift is presented.

7.2 Stability And Control Analysis

The purpose of this Section is to present the stability and control for the Good airplane. This section presents the aerodynamic force and moment coefficients in graph format. The airplane static and dynamic longitudinal stability is presented. A trim diagram was constructed. The airplane dynamic directional stability is presented.

7.2.1 Aerodynamic Force And Moment Coefficients

This sub-section presents the aerodynamic force and moment coefficients for the Good airplane. Reference 16 is used to compute the coefficients. Reference 13, Chapter 4 is used to determine if the computed values fall within the recommended ranges. The values used in the computation of the coefficients, as well as the coefficient values, are tabulated in Tables C.1 through C.3 of Appendix C.

The coefficients are presented in Figures 7.3 through 7.31. Table 7.1 lists the figure numbers, the equation numbers of Reference 16 used in the computation, and the proposed ranges of Reference 13.

TABLE 7.1 Force and Moment Coefficients Figures, Equations and Proposed Ranges.

FIGURE NUMBER	VARIABLE SYMBOL	EQUATION NUMBER (Ref.16)	(Ref.13) RANGE PROPOSED	IS WITHIN RANGE
7.3	C_D	(5.2), p.128	(0.01 to 0.15), p.122	YES
7.4	C_{D_a}	(10.18), p.379	(0.00 to 2.00), p.122	YES
7.5	C_{L_o}	(8.32), p.268	(-.05 to 0.20), p.128	YES
7.6	C_{L_a}	(8.42), p.272	(1.00 to 8.00), p.128	YES
7.7	$C_{L_{d_e}}$	(10.95), p.438	(0.00 to 0.60), p.129	YES
7.8	C_{m_o}	(8.76), p.320	(0.15 to -.15), p.135	YES
7.9	C_{m_a}	(10.19), p.381	(-3.0 to +1.0), p.135	YES
7.10	$C_{m_{d_e}}$	(10.96), p.438	(0.00 to -4.0), p.136	YES
7.11	C_{l_B}	(10.33), p.389	(+0.1 to -0.4), p.146	YES
7.12	$C_{l_{d_A}}$	(10.108), p.446	(0.00 to +0.4), p.149	YES
7.13	$C_{l_{d_R}}$	(10.124), p.461	(-.04 to +.04), p.151	YES

TABLE 7.1 Force and Moment Coefficients Figures, Equations and Proposed Ranges, (cont.).

FIGURE NUMBER	VARIABLE SYMBOL	EQUATION NUMBER (Ref.16)	(Ref.13) RANGE PROPOSED	IS WITHIN RANGE
7.14	C_{y_B}	(10.25), p.383	(-0.1 to -2.0), p.151	YES
7.15	$C_{y_{d_R}}$	(10.123), p.461	(0.00 to 0.50), p.155	YES
7.16	C_{n_B}	(10.40), p.397	(0.00 to 0.40), p.155	YES
7.17	$C_{n_{d_R}}$	(10.125), p.462	(0.00 to -.15), p.159	YES
7.18	$C_{n_{d_A}}$	(10.114), p.448	(-.08 to +.08), p.160	YES
7.19	C_{D_u}	(10.10), p.376	(-.01 to +.30), p.177	YES
7.20	C_{L_u}	(10.11), p.376	(-.20 to +.60), p.177	YES
7.21	C_{m_u}	(10.12), p.377	(-.40 to +.60), p.181	YES
7.22	$C_{L_{\dot{a}}}$	(10.22), p.381	(-5.0 to 15.0), p.185	YES
7.23	$C_{m_{\dot{a}}}$	(10.24), p.382	(0.00 to -10.), p.185	YES

TABLE 7.1 Force and Moment Coefficients Figures, Equations and Proposed Ranges (cont.).

FIGURE NUMBER	VARIABLE SYMBOL	EQUATION NUMBER (Ref.16)	(Ref.13) RANGE PROPOSED	IS WITHIN RANGE
7.24	C_{l_q}	(10.69), p.424	(0.00 to +15.), p.189	YES
7.25	C_{m_q}	(10.75), p.425	(0.00 to -40.), p.189	YES
7.26	C_{y_p}	(10.50), p.417	(-.30 to +.80), p.194	YES
7.27	C_{l_p}	(10.51), p.417	(-.10 to -.80), p.198	YES
7.28	C_{n_p}	(10.61), p.421	(-.50 to +.10), p.200	YES
7.29	C_{y_r}	(10.80), p.428	(0.00 to +1.2), p.202	YES
7.30	C_{l_r}	(10.81), p.428	(0.00 to +.60), p.206	YES
7.31	C_{n_r}	(10.86), p.432	(0.00 to -1.0), p.206	YES

All force and moment coefficients calculated and presented in Figs. 7.3-7.31 are within Reference 13 proposed ranges. All computed force and moment coefficients numerical values can be seen in Table C.3 of Appendix C.

7.2.2 Static and Dynamic Longitudinal Stability

This sub-section presents the static and dynamic longitudinal stability. It is demonstrated that the Good aircraft is longitudinally stable (statically and dynamically), and that it complies to MIL-F-8785C LEVEL 1 longitudinal flying qualities.

7.2.2.1 Static Longitudinal Stability

Reference 12, Section 11.1, p.259 is used to prepare the X-plot of Figure 7.32. There are six curves for the rate at which the aerodynamic center moves aft or forward with variation of horizontal tail area and Mach number. Reference 12, Eqn. 11.1, p.261 is used to generate the six curves. Two additional curves represent the rate at which the center of gravity (most aft and most forward) move aft or forward as a function of tail area. From Figure 7.32 it can be seen that the Good airplane has an adequate amount static margin with its horizontal tail area of 160 square feet.

7.2.2.2 Dynamic Longitudinal Stability

Using the force and moment coefficients calculated in Section 7.2.1, the longitudinal dimensional stability derivatives are calculated for the Good airplane. The equations of Reference 13, Table 6.3, p.413 are used for the computation. Appendix C, Tables C.4.1 through C.4.7 tabulate the computed longitudinal dimensional stability derivatives for eight flight conditions. The eight flight conditions are the following:

1.) Take-off at sealevel (W = 39,508 lbs, V = 106 kts)
2.) Cruise #1 at 5,000 ft (W = 39,508 lbs, V = 250 kts)
3.) Loiter at 5,000 ft (W = 39,508 lbs, V = 150 kts)
4.) Cruise #2 at 5,000 ft (W = 20,932 lbs, V = 250 kts)
5.) Dash-in at 1,000 ft (W = 39,508 lbs, V = 350 kts)
6.) Maneuver at 1,000 ft (W = 30,220 lbs, V = 220 kts, n = 5)
7.) Dash-out at 1,000 ft (W = 20,932 lbs, V = 350 kts)
8.) Landing at sealevel (W = 20,932 lbs, V = 106 kts)

Body fixed moments and products of inertia for the Good aircraft were calculated. The body fixed pitching moment of inertia is required in the computation of some of the longitudinal dimensional stability derivatives. The body fixed rolling, pitching and yawing moments and the products of inertia a gross take-off weight of 39,508 lbs, and empty operating weight of 20,932 lbs are:

I_{xx_B} = (42,279),(38,883)slugs.sqf I_{yy_B} = (94,773),(80,854)slugs.sqf

I_{zz_B} =(102,181),(113,300)slug.sqf I_{zx_B} = (7,806),(6,420) slugs.sqf

The above values are verified with Reference 13, Figs. 2.3-2.5, pp.19-21. Sub-section 7.2.4 discusses inertia transformation from fixed body reference axis system to the stability axes system.

The phugoid and short period modes were analyzed at 8 critical flight conditions. Tables C.4.1 through C.4.7 of Appendix C present the values calculated for the phugoid and short period modes (undamped natural frequencies and damping ratios) for the eight flight conditions. A summary of the phugoid and short period modes is tabulated in Table 7.2. In the same table each flight condition category and parameters are presented.

Table 7.2 Longitudinal Flying Qualities

Variable	Units	Take-off	Cruise		Loiter	Dash-in	Maneuver	Dash-out	Landing
Weight:	[lbs]	39,508	39,508	20,932	39,508	39,508	30,220	20,932	20,932
Speed:	[kts]	106	250	250	150	350	220	350	106
Mach number:		0.16	0.385	0.385	0.23	0.53	0.33	0.53	0.16
Altitude:	[ft]	0	5,000	5,000	5,000	1,000	1,000	1,000	0
Load factor:		1	1	1	1	1	5	1	1
I_{yy}	[slugs.lbs]	94,773	94,773	80,854	94,773	94,773	87,813	80,854	80,854
CATEGORY		C	B	B	B	A	A	A	C
Phugoid mode damping ratio: Reference 13, Eqn.(6.113), p.430; Reference 14, Sec.3.2.1.2, p.291.									
$zeta_p$		-0.336	0.202	0.391	0.088	0.304	1.417	0.576	-0.055
LEVEL		*	1	1	1	1	1	1	*
Undamped short period natural frequency: Reference 13, Eqn.(6.101), p.426; Reference 14, Figs.B1-B3, p.291.									
$w_{n_{S.P.}}$	[rad/sec]	1.557	3.595	3.501	2.285	5.251	3.133	5.351	1.563
n/a	[g's/rad]	3.565	23.06	43.51	8.370	57.06	20.15	107.7	6.645
LEVEL		1	1	1	1	1	1	1	1
Short period damping ratio: Reference 13, Eqn.(6.102), p.426; Reference 14, Table IV, p.292.									
$zeta_{S.P.}$		0.827	0.906	1.235	0.819	1.116	1.053	1.451	1.093
LEVEL		1	1	1	1	1	1	2	1

* unstable

LEVEL 1 flying qualities are verified with the requirements of MIL-F-8785C: military specification, flying qualities of piloted airplanes. It is demonstrated that the Good airplane satisfies the MIL-F-8785C Level 1 longitudinal flying quality for all eight flight conditions. The flying qualities are clearly adequate for the mission phases of the eight flight conditions.

7.2.3 The Trim Diagram

The methods of References 16 and 17 are used to construct the trim diagram. The flight conditions for which the trim diagram is constructed are the following:

1.) Gross Take-off weight: W_{TO} = 39,508 lbs

2.) Most aft center of gravity location: $\bar{x}_{cg_{aft}}$ = 0.5567

3.) Most forward center of gravity location: $\bar{x}_{cg_{fwd}}$ = 0.4667

4.) Elevator deflection angle: d_e = + 30, - 30 degrees

5.) The lift curve slope is at M = 0.35.

6.) Planform areas: S = 890 sqf, S_h = 160 wsqf

7.) Aspect ratios: A = 8, A_h = 5.2

8.) $\bar{x}_{ref}$ = 0.5117

9.) Sealevel ISA condition.

10.) Load factor: n = 1.0

Figure 7.33 presents the trim diagram for the above listed airplane characteristics. On the figure it can be seen that the maximum airplane lift coefficient without elevator deflection is 1.36. The appropriate lift curve slopes with elevator deflections are offseted by 0.2 for 30 degrees of deflection. The pitch break is curved after consideration of the following three criteria:

1.) From Reference 17, Figure 5.9, p.266 the Good airplane wing (A=8, leading edge sweep angle = 16 degrees) displays a marginal to unstable pitch break. This is due to the combination of relatively large aspect ratio and leading edge sweep angle.

2.) From Reference 17, Figure 5.10, p.267 the horizontal tail of the Good airplane is located in Region 'C'. (The horizontal tail moment arm / m.g.c = 3.318, and the horizontal tail height / m.g.c. = 1). The horizontal tail will enter the wing wake only when the latter is unstable. This is stated in Reference 17, p.265.

3.) From Reference 17, Fig.5.11, p.267 there is recovery since C_m remains negative with maximum elevator deflection (+30 degrees).

Taking into account the above three pitch break criteria, the trim diagram is drawn with a starting unstable pitch break that becomes stable shortly after. On Fig.7.33 the most aft and forward center of gravity pitching moments are graphedand it can be seen that 30 degrees of elevator deflection is more than enough to trim the airplane. Actually in the present flight conditions an elevator deflection angle of 10 degrees is adequate.

7.2.4 Dynamic Lateral-Directional Stability

The dynamic lateral-directional stability for the fighter aircraft is analyzed. It is demonstrated that the Good aircraft is dynamically directionally stable. The airplane does comply to MIL-F-8785C LEVEL 1 lateral-directional flying qualities.

Using the force and moment coefficients calculated in Sub-section 7.2.1, the lateral-directional dimensional stability derivatives are calculated for the Good airplane. The equations of Reference 13, Table 6.8, p.445 are used for the computation. Tables C.4.1 through C.4.7 Appendix C tabulate the computed lateral-directional dimensional stability derivatives values for the eight flight conditions.

The moments of inertia (body-fixed reference system) are transformed to the stability axes system, using Reference 13, Eqn.(6.140), p.442. The moments of inertia I_{xx_s}, I_{zz_s} and I_{xz_s} are tabulated in Table C.3 of Appendix C, and the moment of inertia ratios A_1 (I_{xz}/I_{xx_s}) and B_1 (I_{xz}/I_{zz_s}) are presented in Tables C.4.1 through C.4.7.

Eight flight conditions are analyzed for the Dutch roll mode, maximum roll mode constant, and spiral stability (minimum time to double amplitude). Table 7.3 summarizes the lateral-directional flying qualities.

TABLE 7.3 Lateral-Directional Flying Qualities

Variable	Units	Take-off	Cruise		Loiter	Dash-in	Maneuver	Dash-out	Landing
Weight:	[lbs]	39,508	39,508	20,932	39,508	39,508	30,220	20,932	20,932
Speed:	[kts]	106	250	250	150	350	220	350	106
Mach number:		0.16	0.385	0.385	0.23	0.53	0.33	0.53	0.16
Altitude:	[ft]	0	5,000	5,000	5,000	1,000	1,000	1,000	0
Load factor:		1	1	1	1	1	5	1	1
CATEGORY		C	B	B	B	A	A	A	C
Dutch roll damping ratio: Reference 14, Eqn.(3.27), p.89; Reference 14, Table VI, p.297									
$zeta_D$		0.222	0.209	0.214	0.208	0.225	0.213	0.230	0.228
LEVEL		1	1	1	1	1	2	1	1
Dutch roll undamped natural frequency: Reference 14, Eqn.(3.26), p.89; Reference 14, Table VI, p.297									
w_{n_D}	[rad/sec]	1.917	4.667	4.365	2.905	6.960	4.244	6.510	1.798
LEVEL		1	1	1	1	1	1	1	1
Reference 14, Table VI, p.297									
$zeta_D w_{n_D}$		0.425	0.977	0.934	0.604	1.565	0.905	1.498	0.411
LEVEL		1	1	1	1	1	-	1	1

Table 7.3 Lateral-Directional Flying Qualities

Variable	Units	Take-off	Cruise		Loiter	Dash-in	Maneuver	Dash-out	Landing
Weight:	[lbs]	39,508	39,508	20,932	39,508	39,508	30,220	20,932	20,932
Speed:	[kts]	106	250	250	150	350	220	350	106
Mach number:		0.16	0.385	0.385	0.23	0.53	0.33	0.53	0.16
Altitude:	[ft]	0	5,000	5,000	5,000	1,000	1,000	1,000	0
Load factor:		1	1	1	1	1	5	1	1
CATEGORY		C	B	B	B	A	A	A	C
Roll mode time constant: Reference 13, Eqn.(6.173), p.458; Reference 14, Table VII, p.297									
T_R	[sec]	0.168	0.064	0.059	0.112	0.034	0.061	0.031	0.156
LEVEL		1	1	1	1	1	1	1	1
Spiral stability - time to double amplitude: Reference 13, Eqn.(B6), p.543; Reference 14, Table VIII, p.297									
T_{2_s}	[sec]	4.92	31.28	36.55	12.65	61.99	38.36	67.78	68.27
LEVEL		3	1	1	2	1	1	1	1

Except for the take-off and loiter time flight phases, the aircraft is dynamically stable (lateral-directional). The Good airplane satisfies the requirements of MIL-F-8785C.

The Good airplane does not satisfy level 1 flying qualities at take-off and loiter flight conditions for the time-to-double amplitude in the spiral mode. A method for 'equivalent stability derivative' could be used to determine how much stability augmentation is needed to achieve level 1 handling quality at take-off and loiter in the spiral mode.

The time-to-double the amplitude in the spiral mode can be modified by changing the dimensional stability derivative L_B. C_{l_B} has a very powerful effect on the time-to-double the amplitude T_{2s}.

For the take-off flight condition the time-to-double the amplitude is 4.92 seconds. This is below the level 2 flight category C requirement of Reference 14, Table VII p. 297. It is desired to increase the time-to-double the amplitude to T_{2s} = 12 sec. This can be done by raising C_{l_B} from its basic value of -0.041/rad to -0.246/rad.

The rolling moment due to sideslip angle can be increased negatively by giving dihedral to the wing or with a stability augmentation system.

7.3 Stability and Control Summary

The aerodynamic forces and moments coefficients for the Good airplane were calculated and the results are presented. The values for the coefficients over a Mach number envelope (0 to 0.55) are tabulated in Table C.3 of Appendix C. It is verified that all the calculated coefficients are within the recommended ranges of Reference 13, Chapter 4.

The static (steady state) stability criteria of Reference 13, Chapter 5 are satisfied. The dynamic stability and response characteristics are presented. The good airplane does satisfy the MIL-F-8785C Level I requirements for longitudinal dynamic stability. This is verified for the following eight flight conditions:

1.) Take-off (at gross take-off weight, 0 ft)
2.) Cruise (at gross take-off weight, 5,000 ft)
3.) Cruise (at operating empty weight, 5,000 ft)
4.) Loiter (at gross take-off weight, 5,000 ft)
5.) Dash-in (at gross take-off weight, 1,000 ft)
6.) Maneuver (at weight between W_{TO} & W_{OE}, 1,000 ft, n=5)
7.) Dash-out (at operating empty weight, 1,000 ft)
8.) Landing (at operating empty weight, 0 ft)

The trim diagram at gross take-off weight, sealevel and unit load factor was constructed.

It was found that the Good airplane does comply to MIL-F-8785C Level 1 flying qualities in all category flight phases and classes for the dynamic lateral-directional stability (except for take-off and loiter flight conditions).

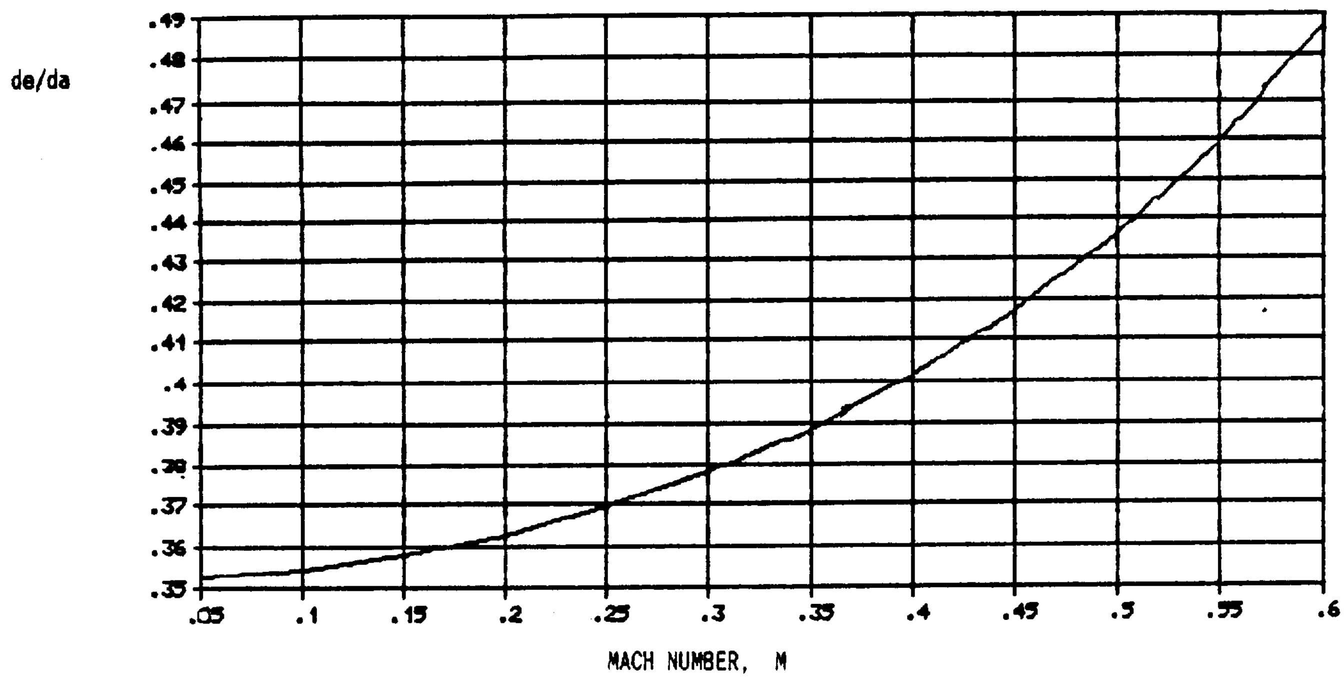

Figure 7.1 Downwash gradient variation at the horizontal tail with Mach number.

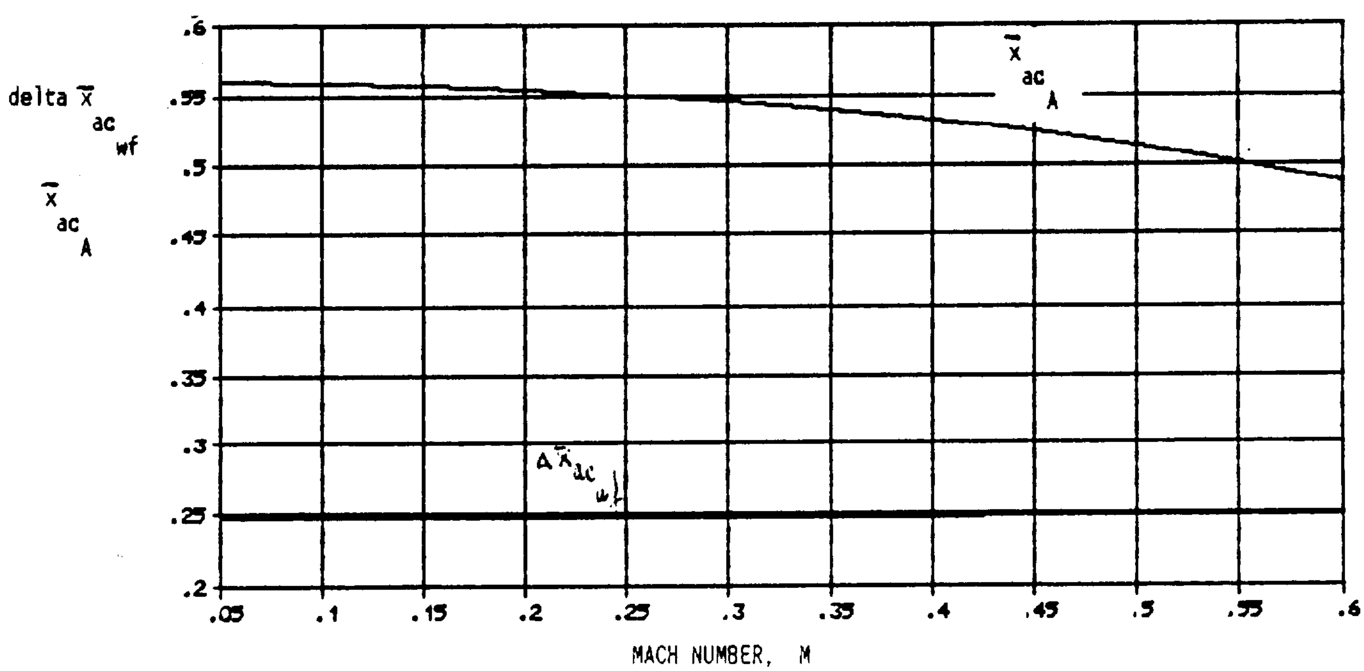

Figure 7.2 Shift in airplane aerodynamic center location with variation of Mach number.

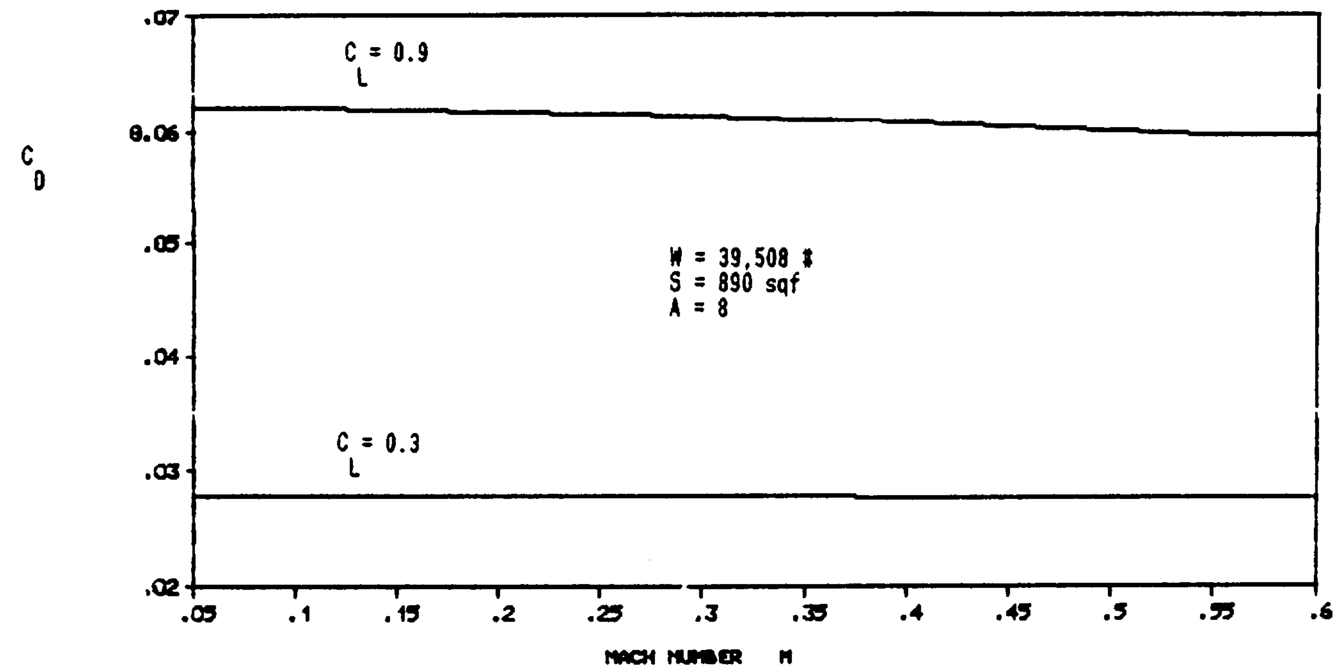

Figure 7.3 Airplane drag coefficient variation with Mach number.

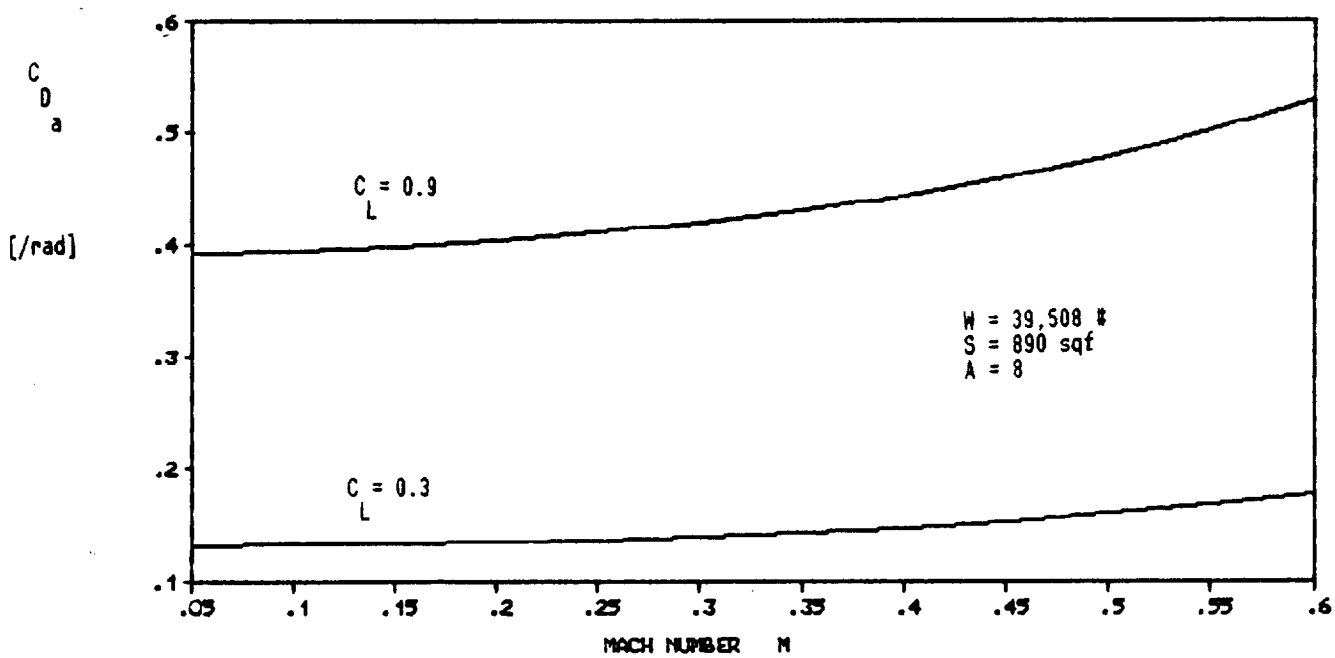

Figure 7.4 Variation of drag coefficient with angle of attack over the Mach number range.

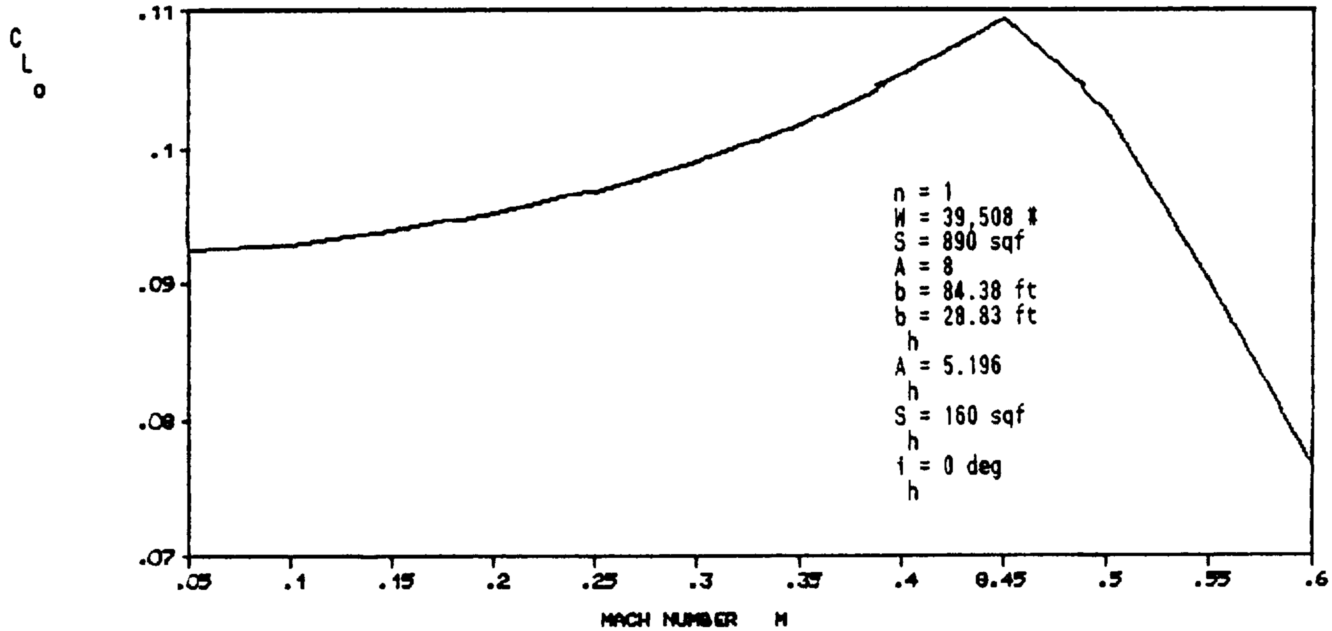

Figure 7.5 Lift coefficient for zero angle of attack, zero elevator angle and zero stabilizer angle, variation with Mach number.

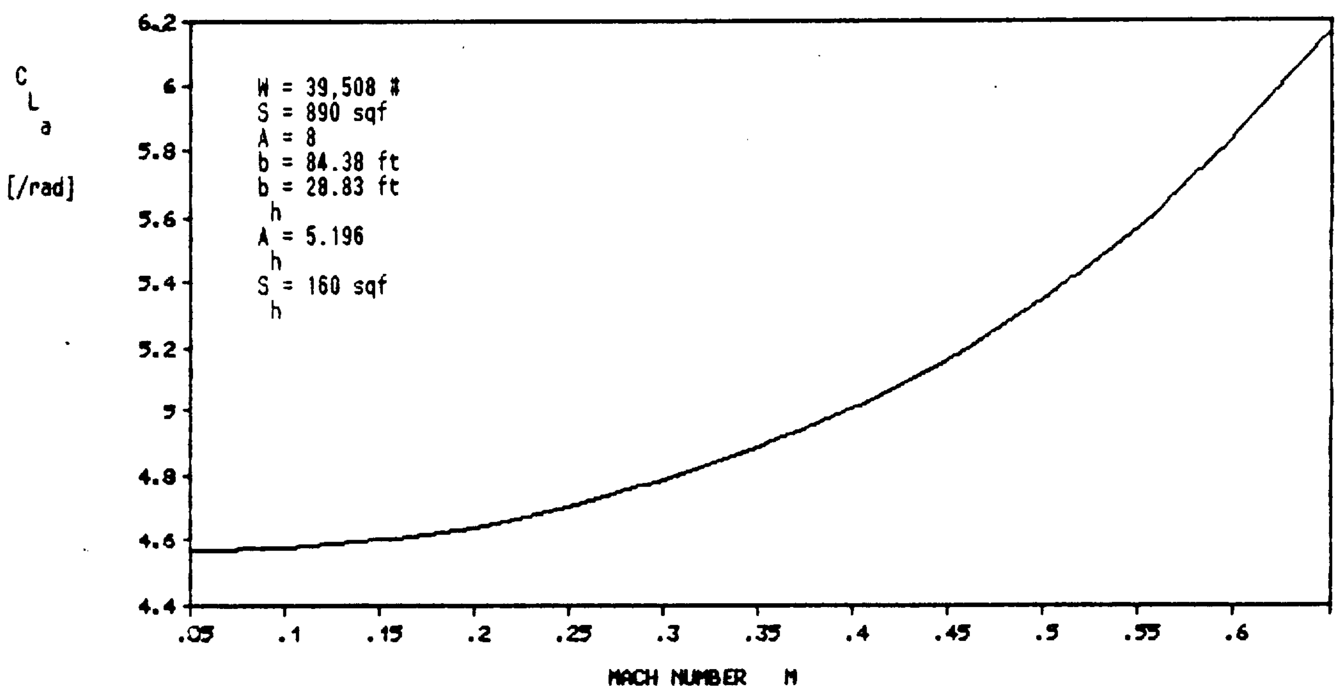

Figure 7.6 Airplane lift curve slope variation with Mach number.

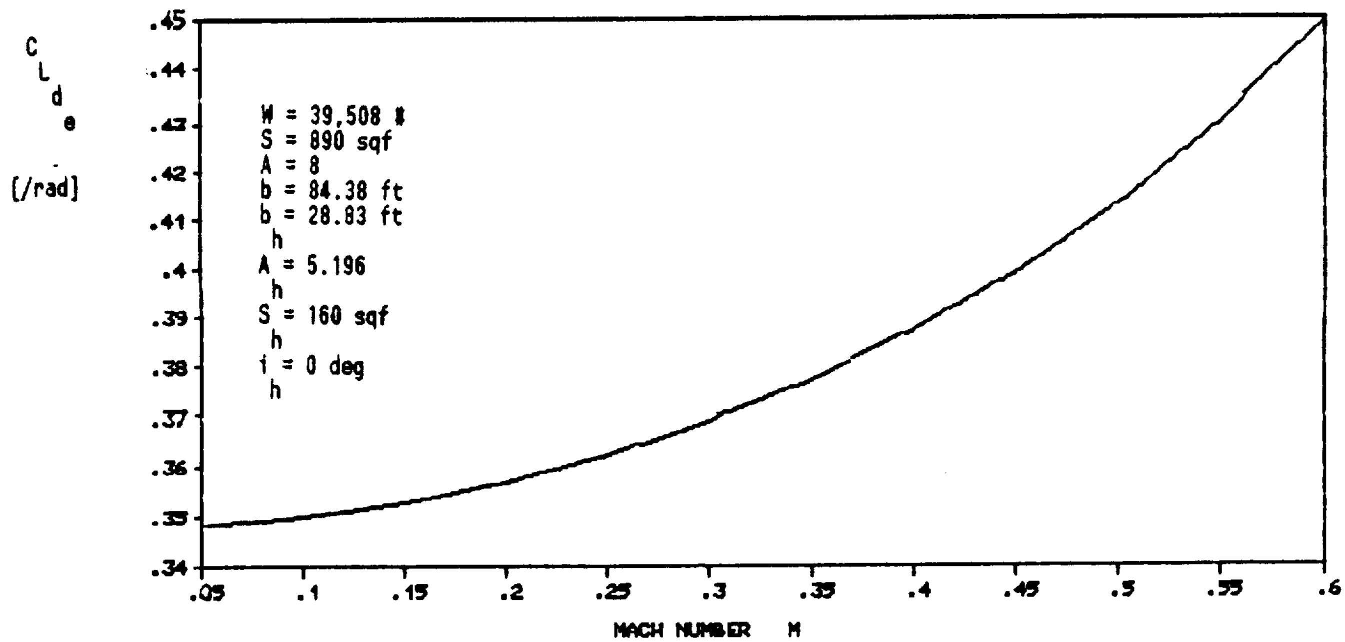

Figure 7.7 Variation of lift coefficient with elevator angle, variation with Mach number.

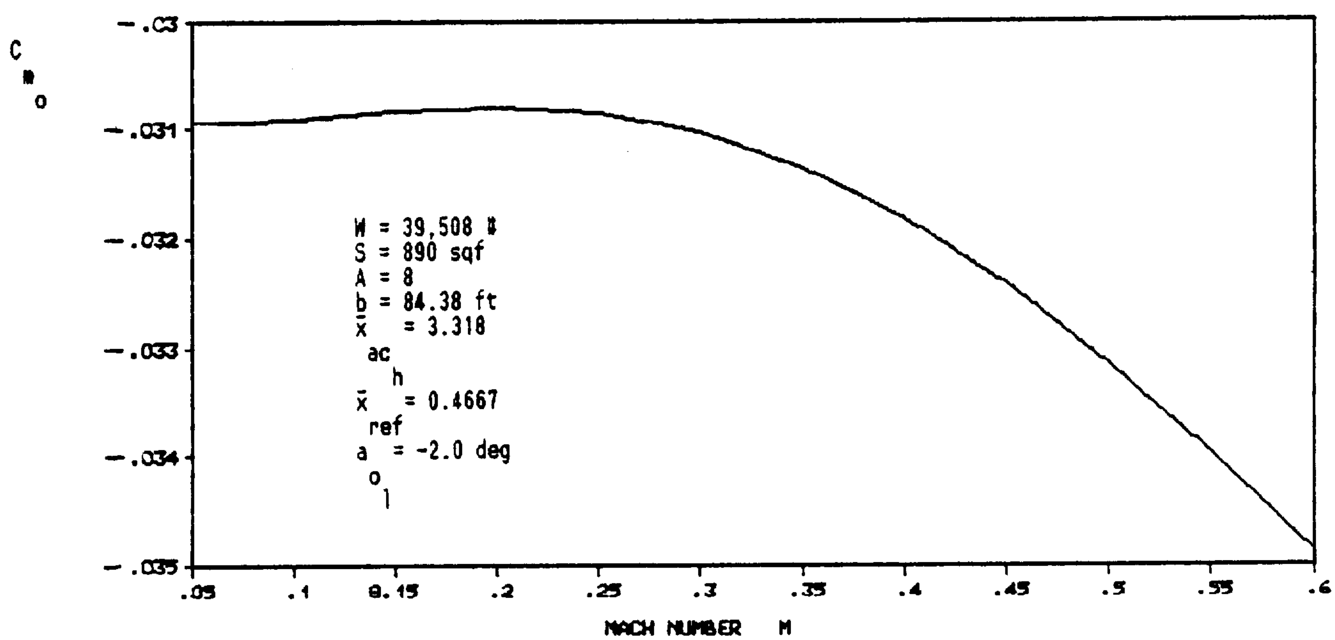

Figure 7.8 Pitching moment coefficient for zero angle of attack, zero elevator angle and zero stabilizer angle, variation with Mach number.

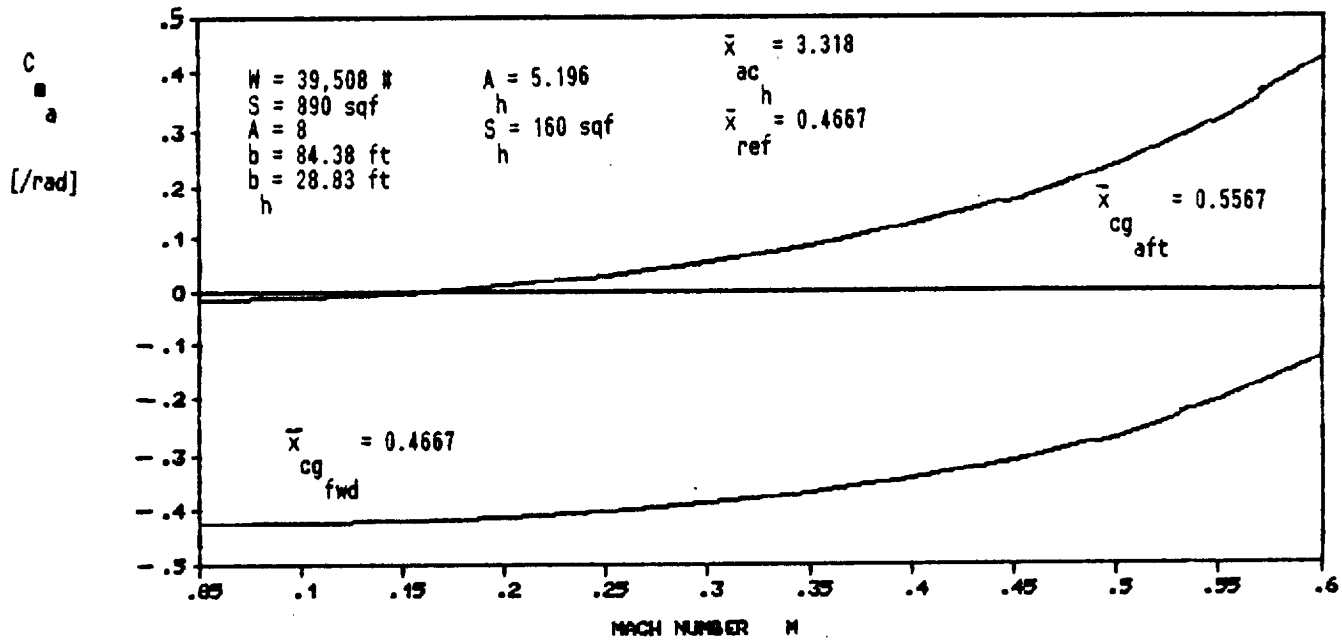

Figure 7.9 Variation of pitching moment coefficient with angle of attack (i.e. static longitudinal stability), versus Mach number.

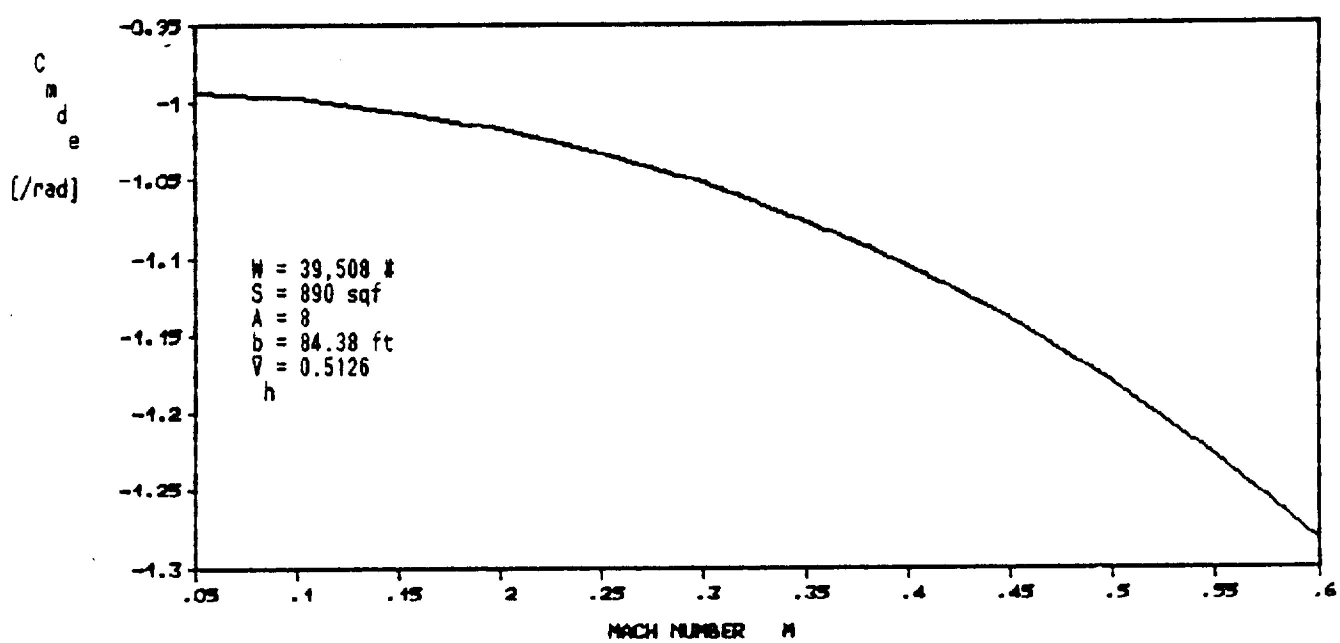

Figure 7.10 Variation of pitching moment coefficient with elevator angle (i.e. longitudinal control power), versus Mach number.

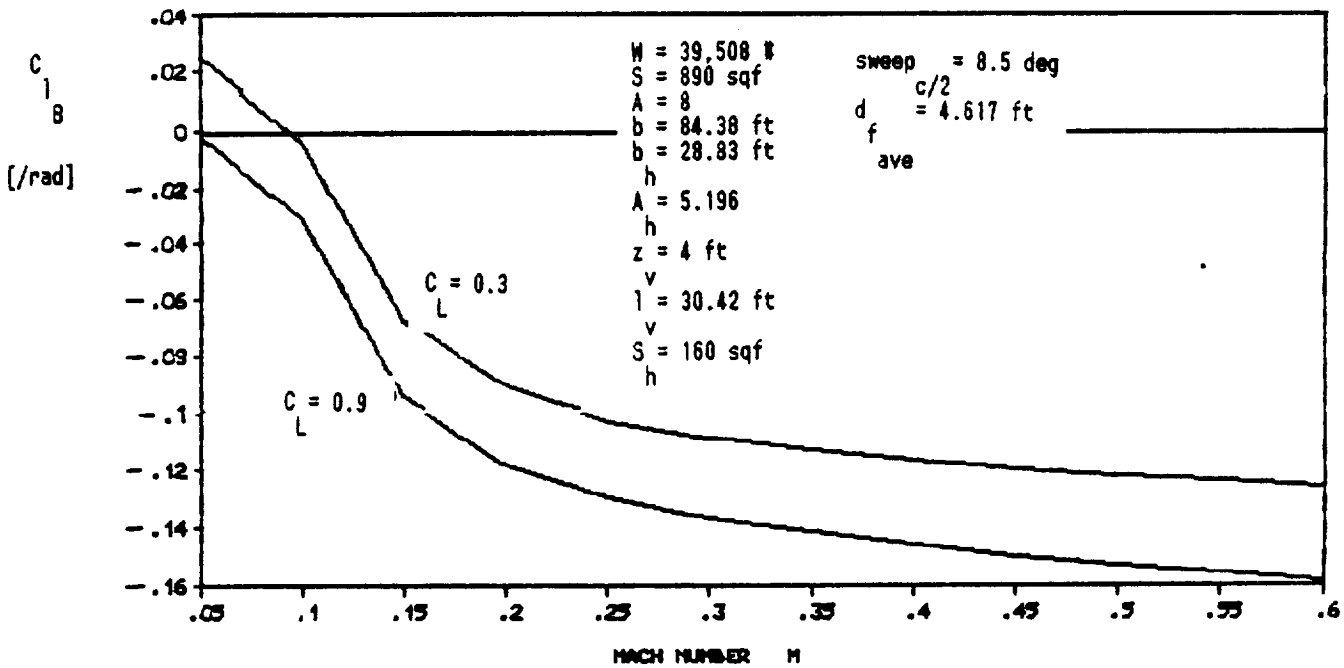

Figure 7.11 Variation of rolling moment coefficient with sideslip angle (i.e. dihedral angle), variation with Mach number.

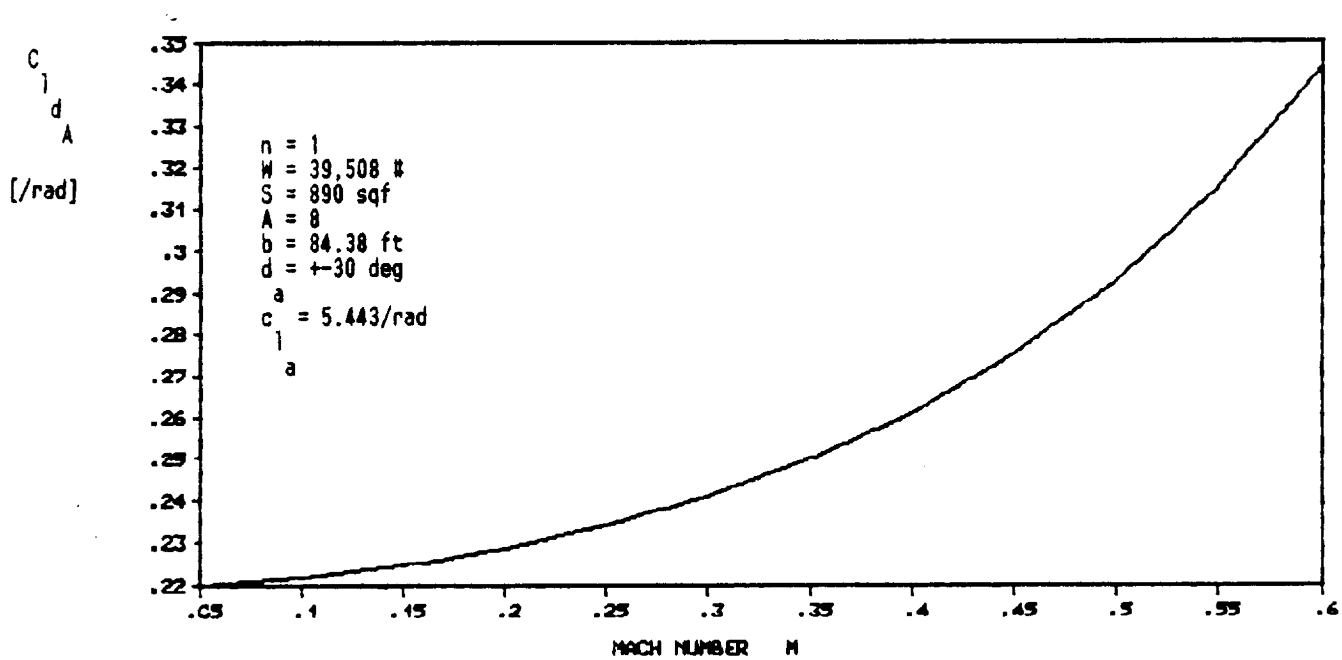

Figure 7.12 Variation of rolling moment coefficient with aileron angle (i.e. lateral control power), variation with Mach number.

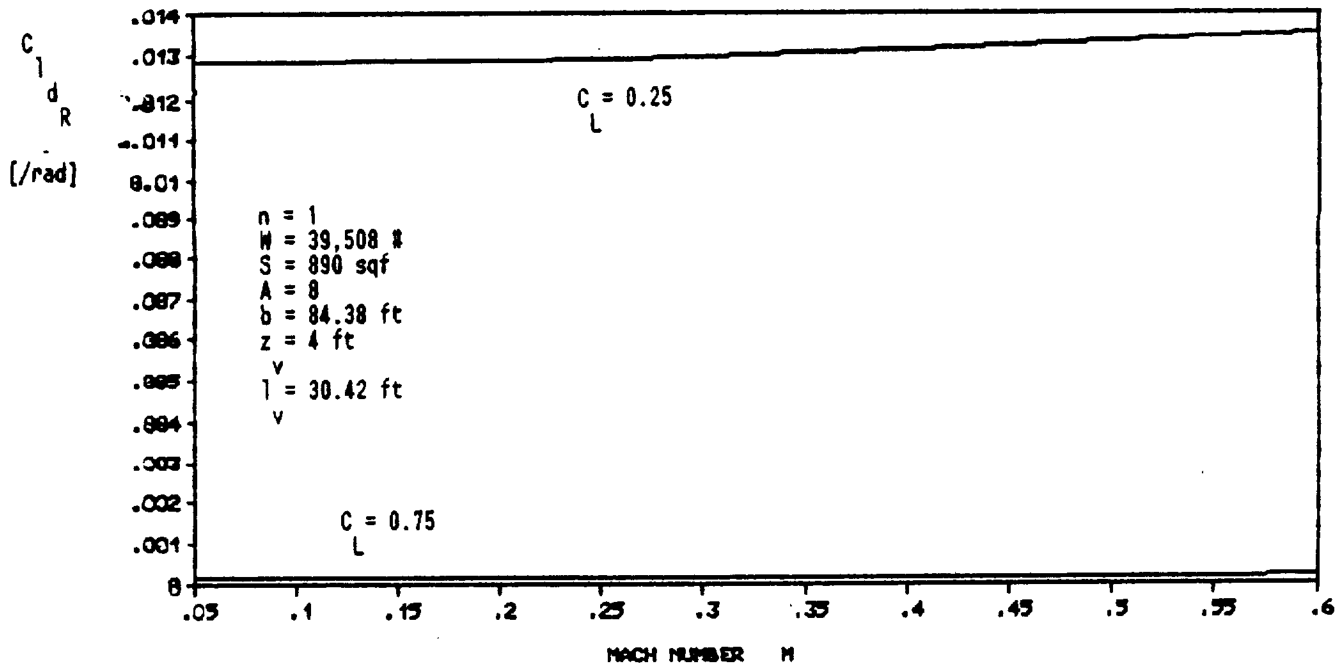

Figure 7.13 Variation of rolling moment coefficient with rudder angle, variation with Mach number.

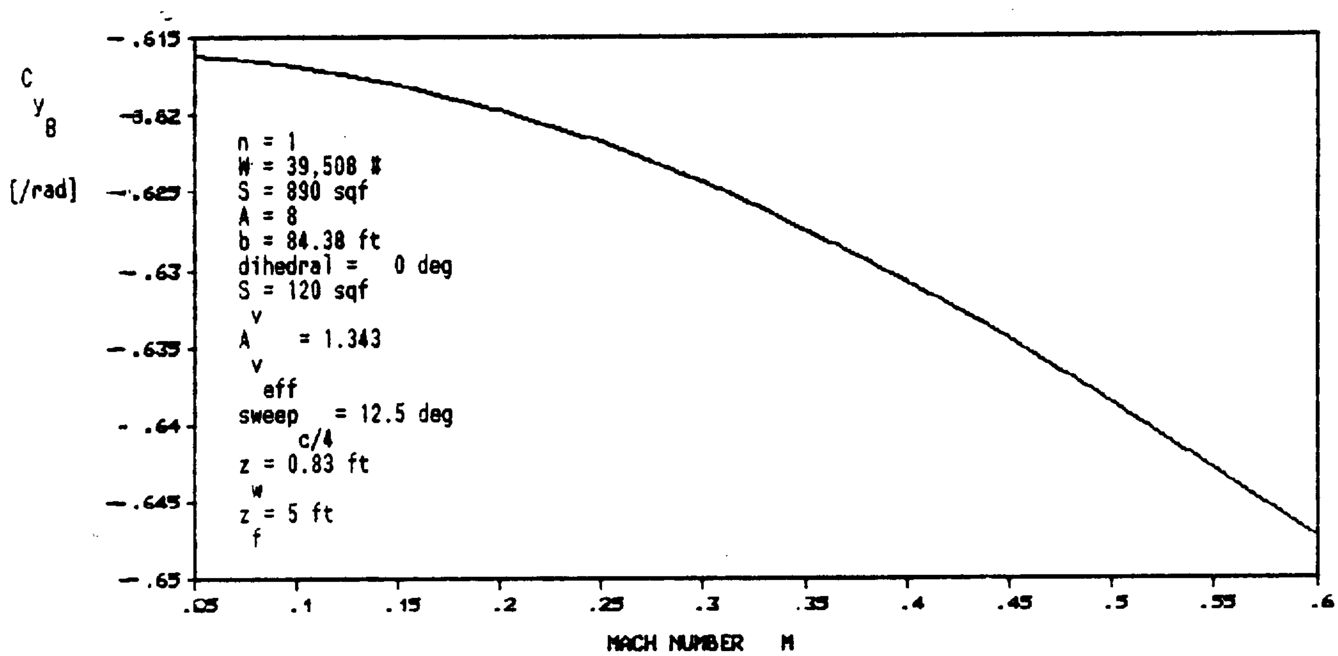

Figure 7.14 Variation of side force coefficient with sideslip angle, variation with Mach number.

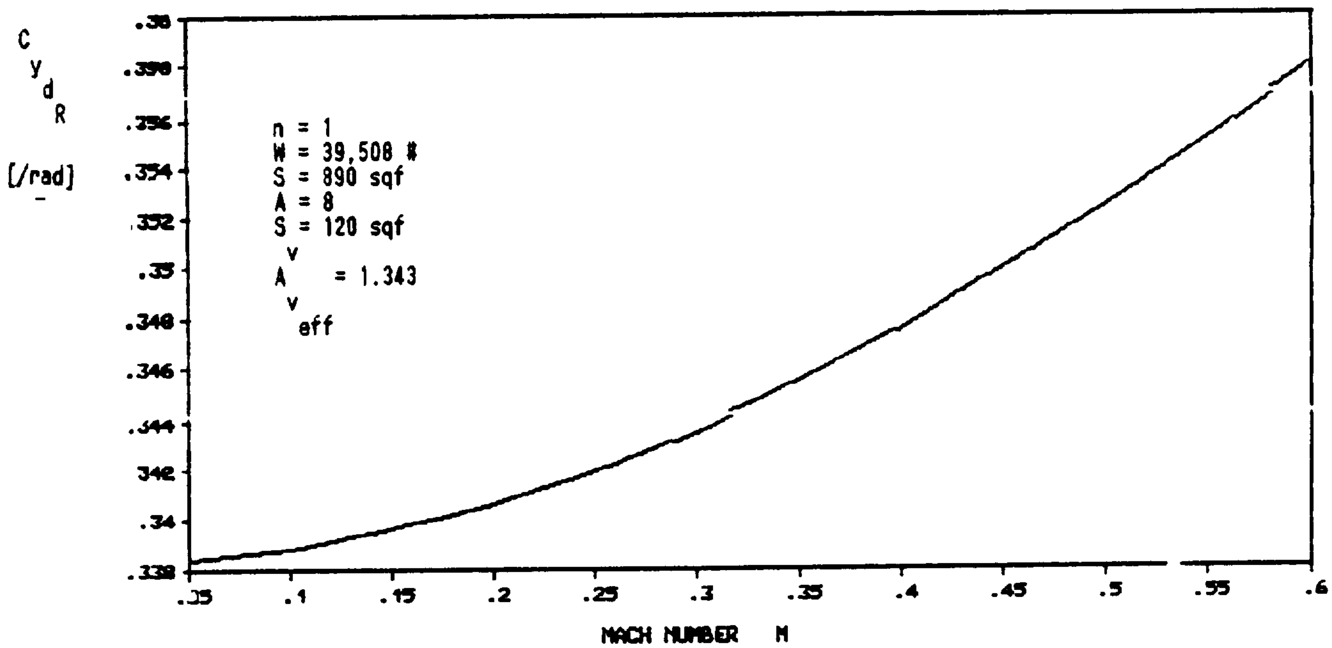

Figure 7.15 Variation of side force coefficient with rudder angle, variation with Mach number.

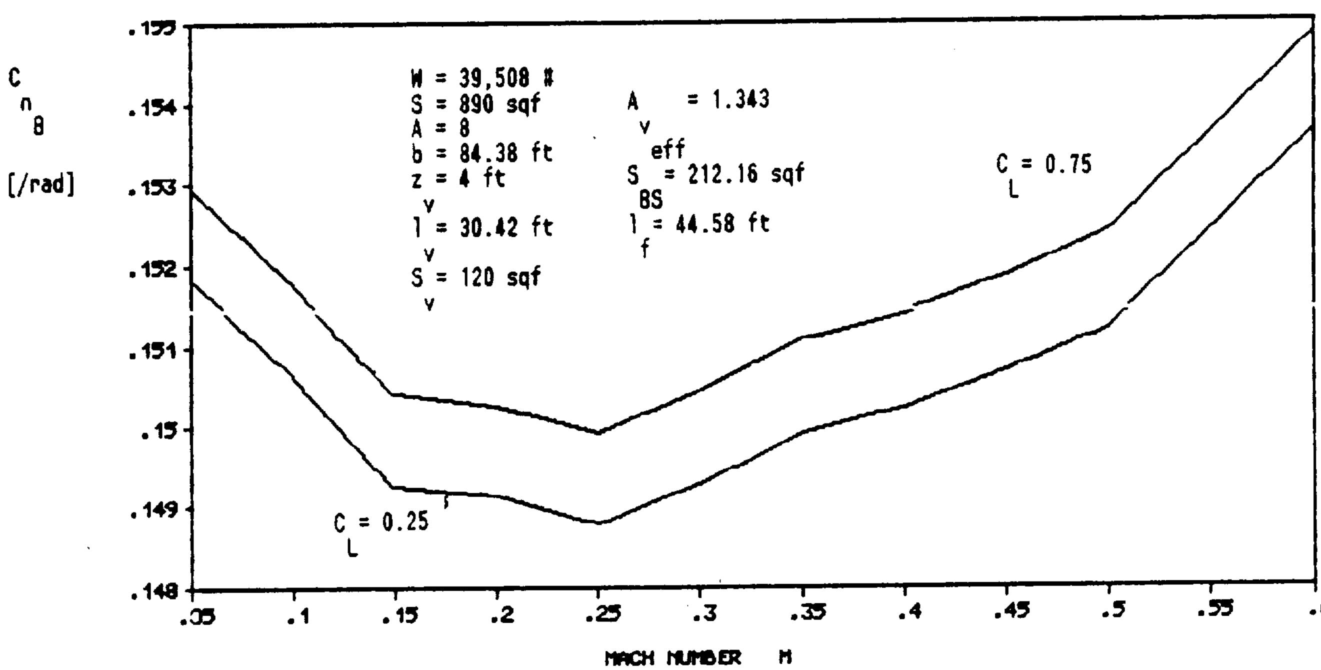

Figure 7.16 Variation of yawing moment coefficient with sideslip angle, variation with Mach number.

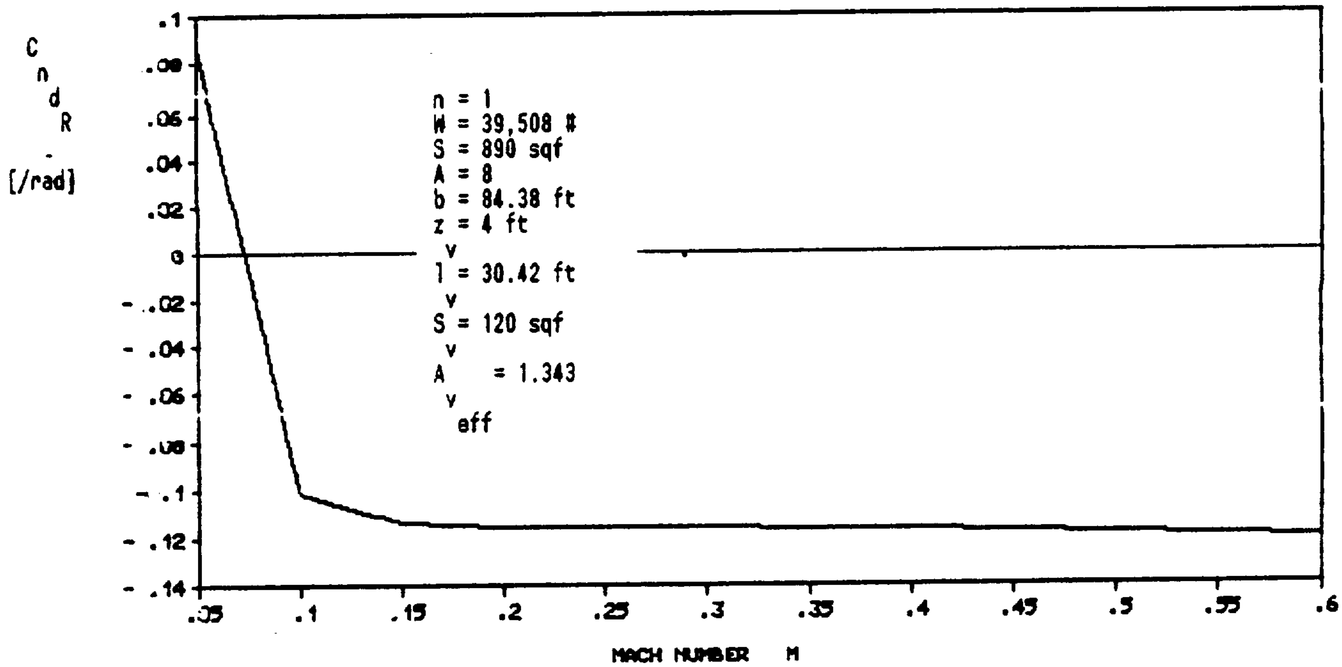

Figure 7.17 Variation of yawing moment coefficient with rudder angle, variation with Mach number.

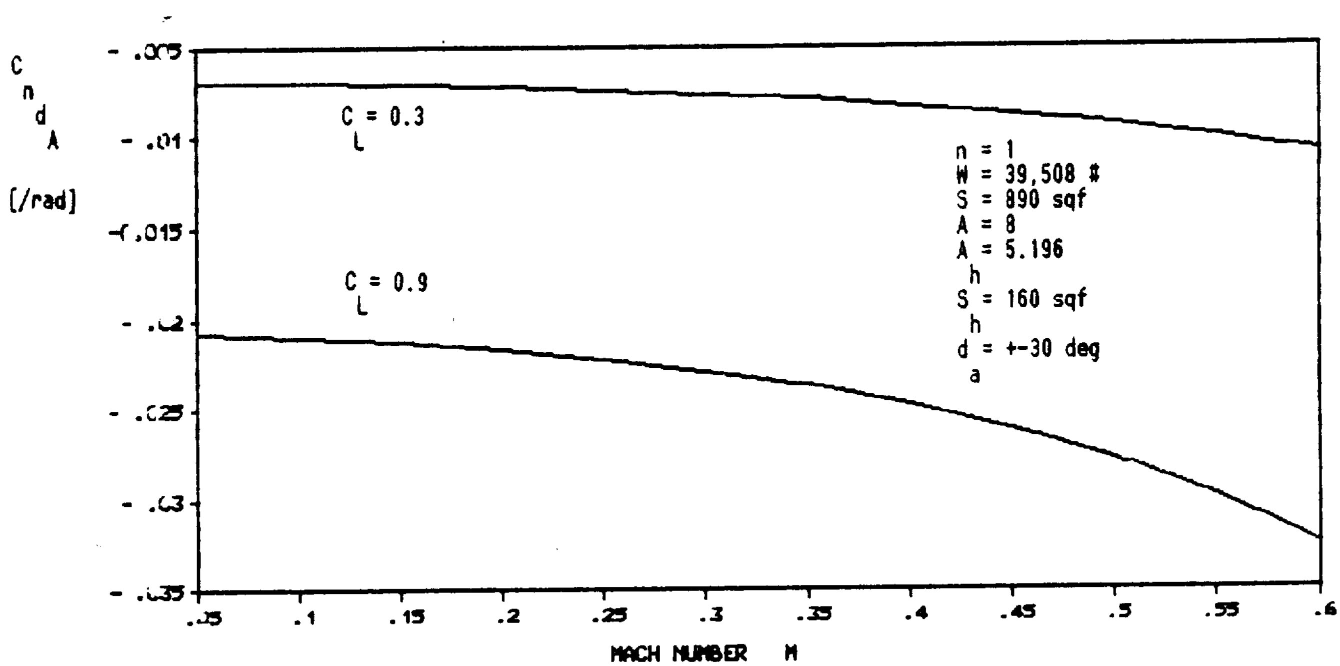

Figure 7.18 Variation of yawing moment coefficient with aileron angle, variation with Mach number.

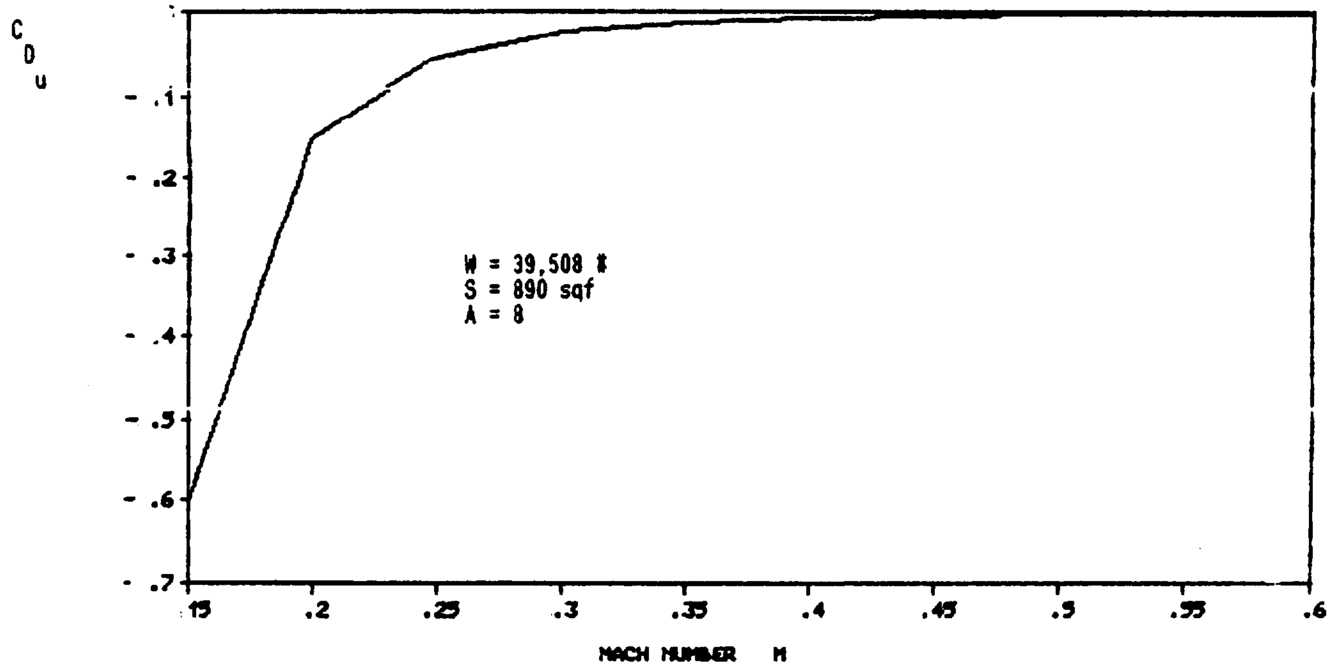

Figure 7.19 Variation of drag coefficient with speed (i.e. speed damping), variation with Mach number.

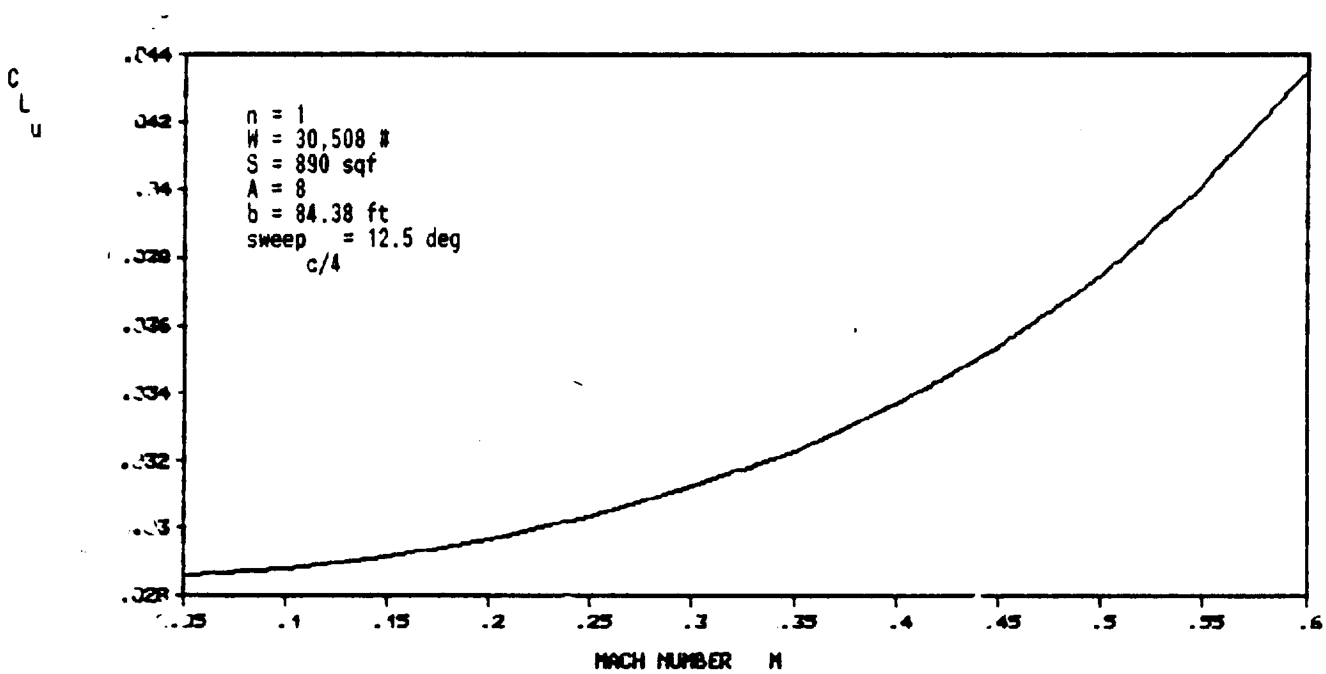

Figure 7.20 Variation of lift coefficient with speed, variation with Mach number.

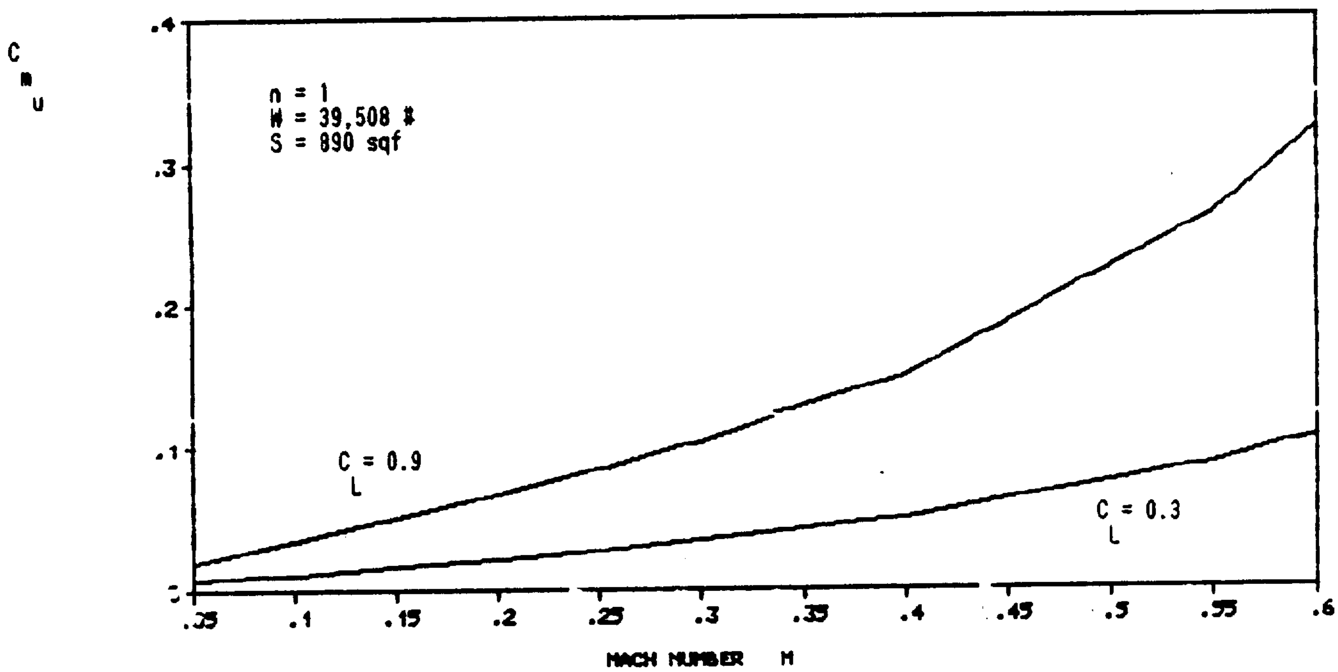

Figure 7.21 Variation of pitching moment coefficient with speed, variation with Mach number.

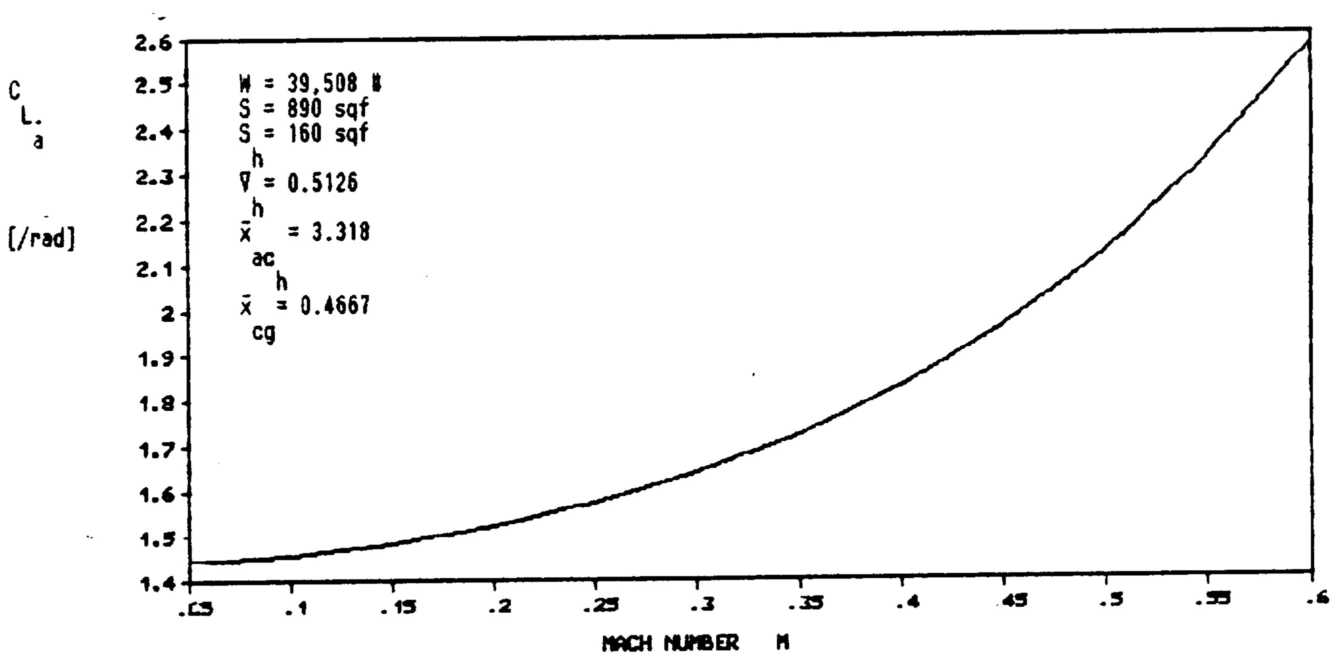

Figure 7.22 Variation of lift coefficient with rate of change of angle of attack, variation with Mach number.

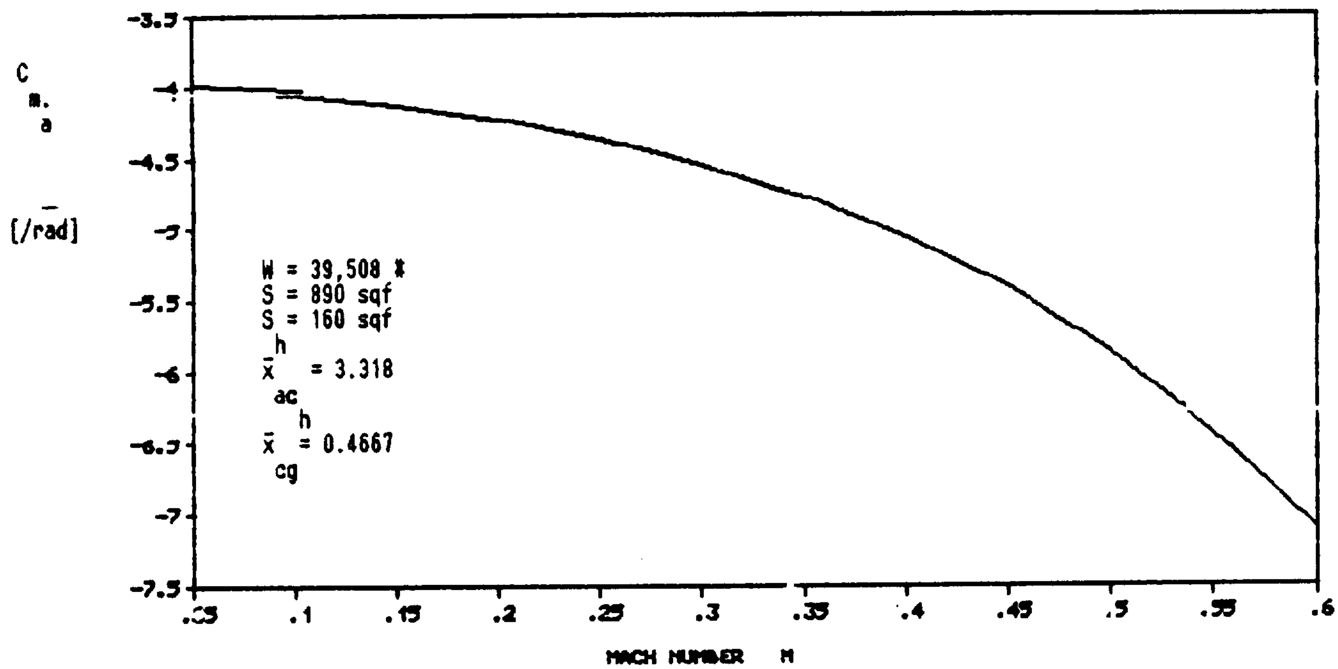

Figure 7.23 Variation of pitching moment coefficient with rate of change of angle of attack, variation with Mach number.

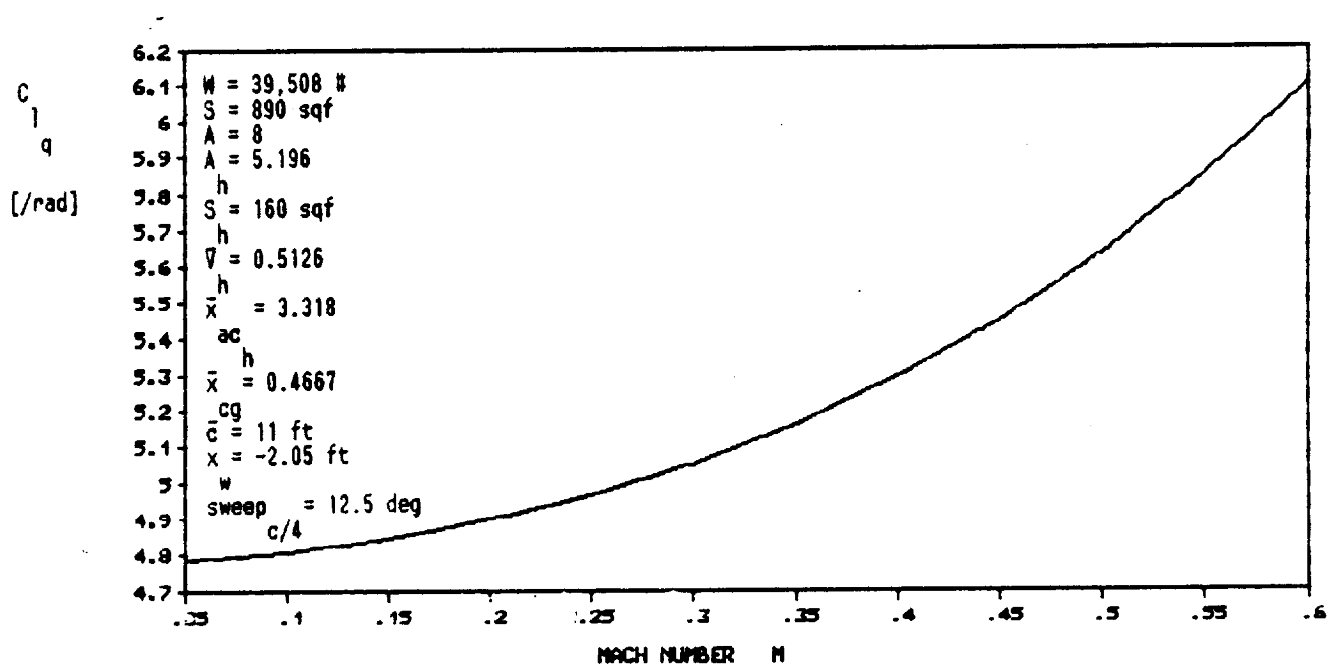

Figure 7.24 Variation of lift coefficient with pitch rate, variation with Mach number.

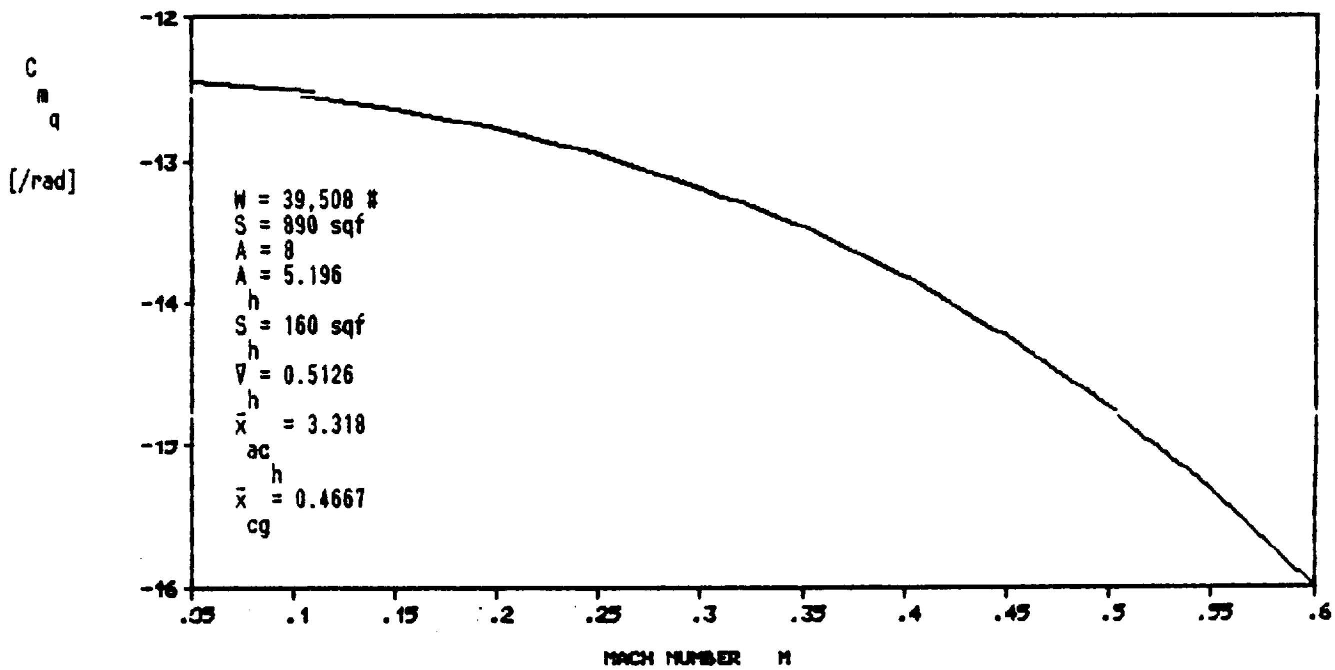

Figure 7.25 Variation of pitching moment coefficient with pitch rate, variation with Mach number.

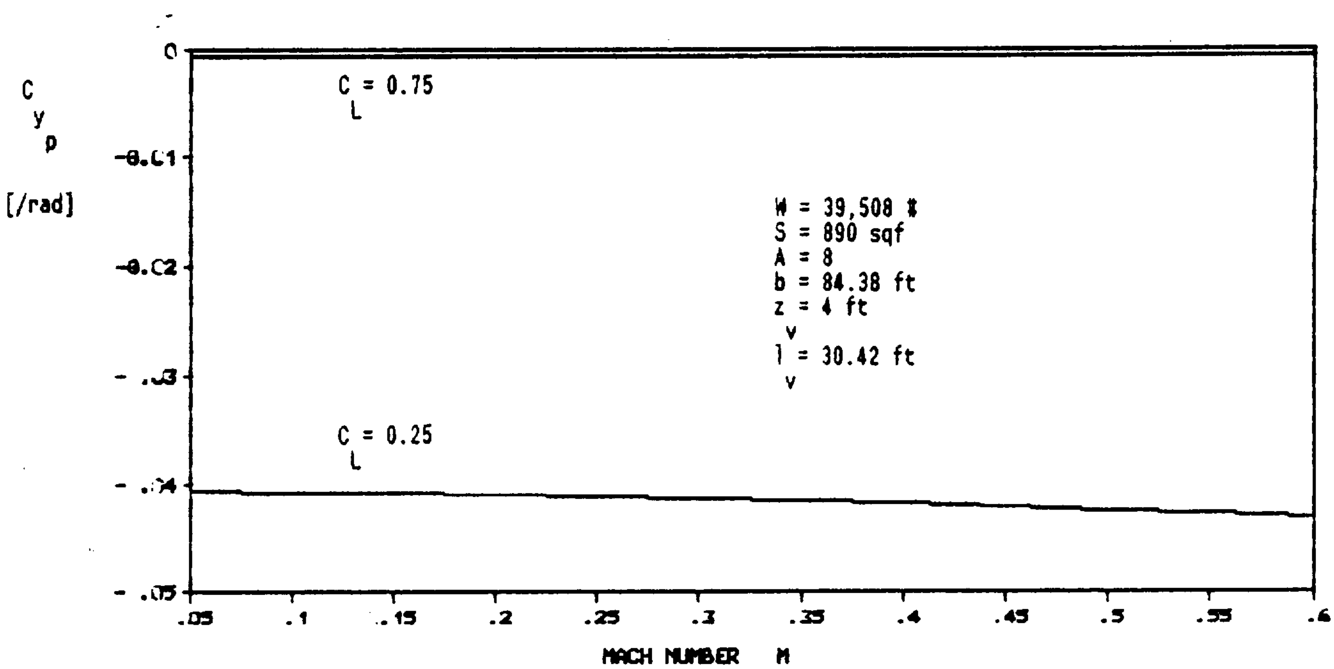

Figure 7.26 Variation of side force coefficient with roll rate, variation with Mach number.

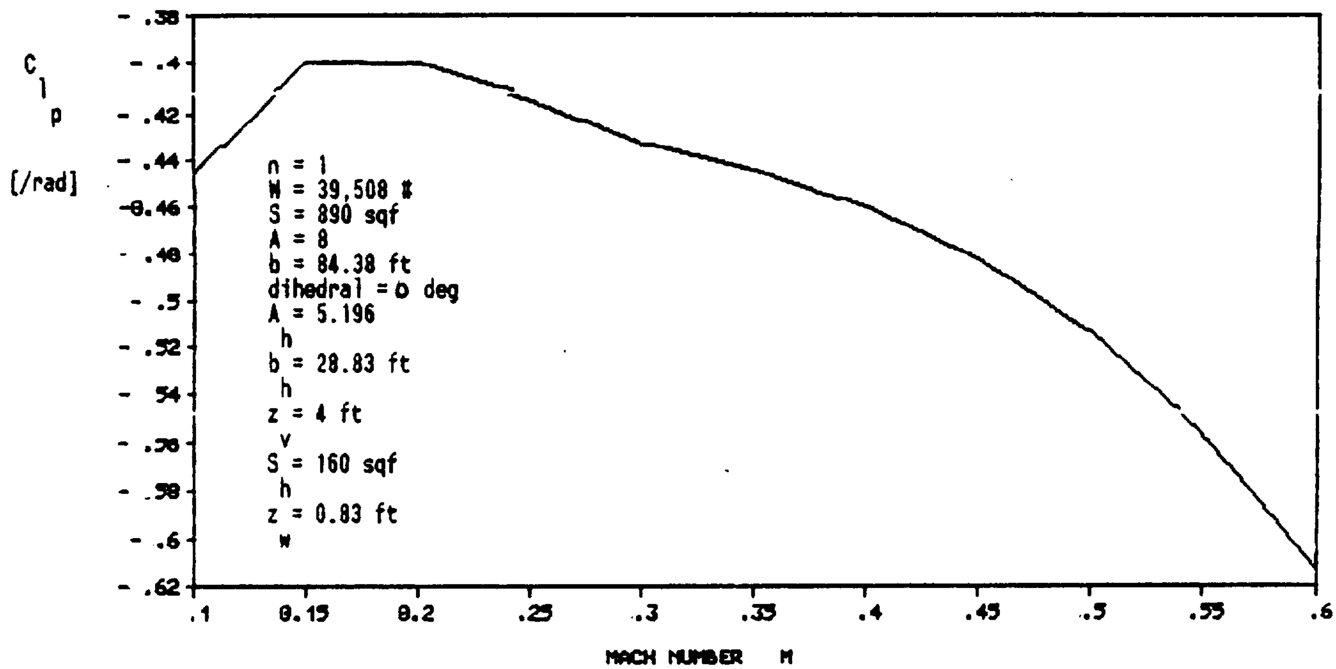

Figure 7.27 Variation of rolling moment coefficient with roll rate, variation with Mach number.

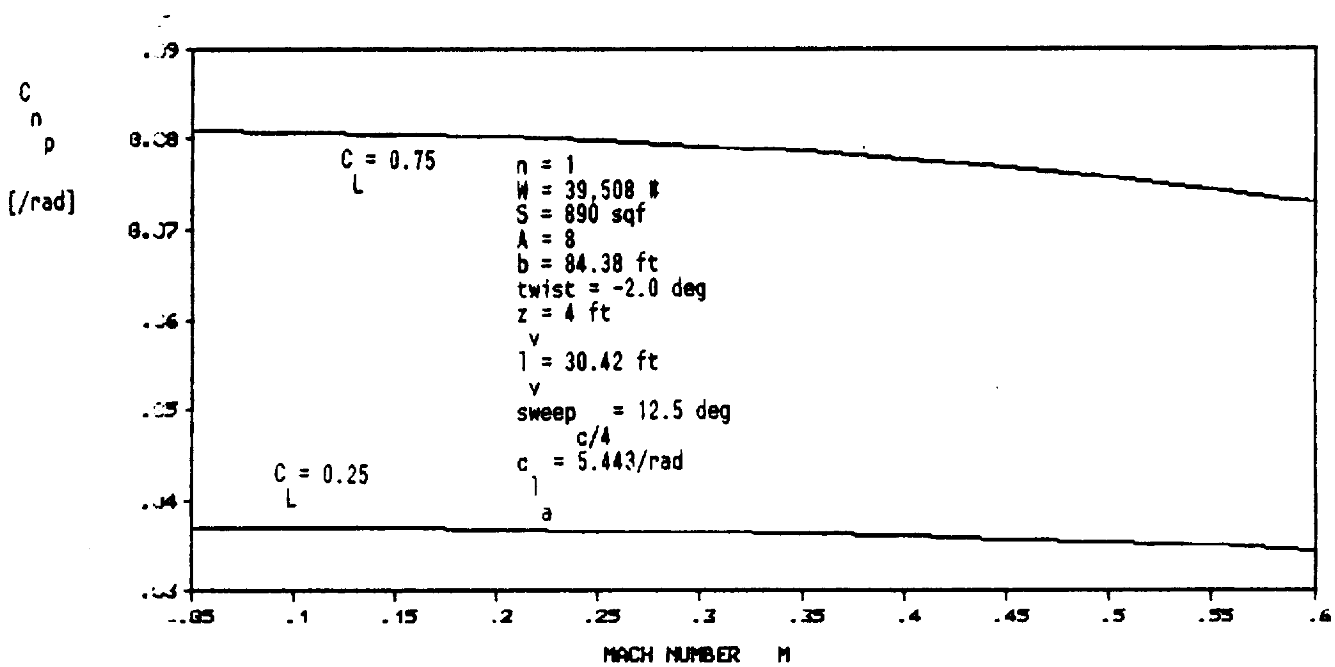

Figure 7.28 Variation of yawing moment coefficient with roll rate, variation with Mach number.

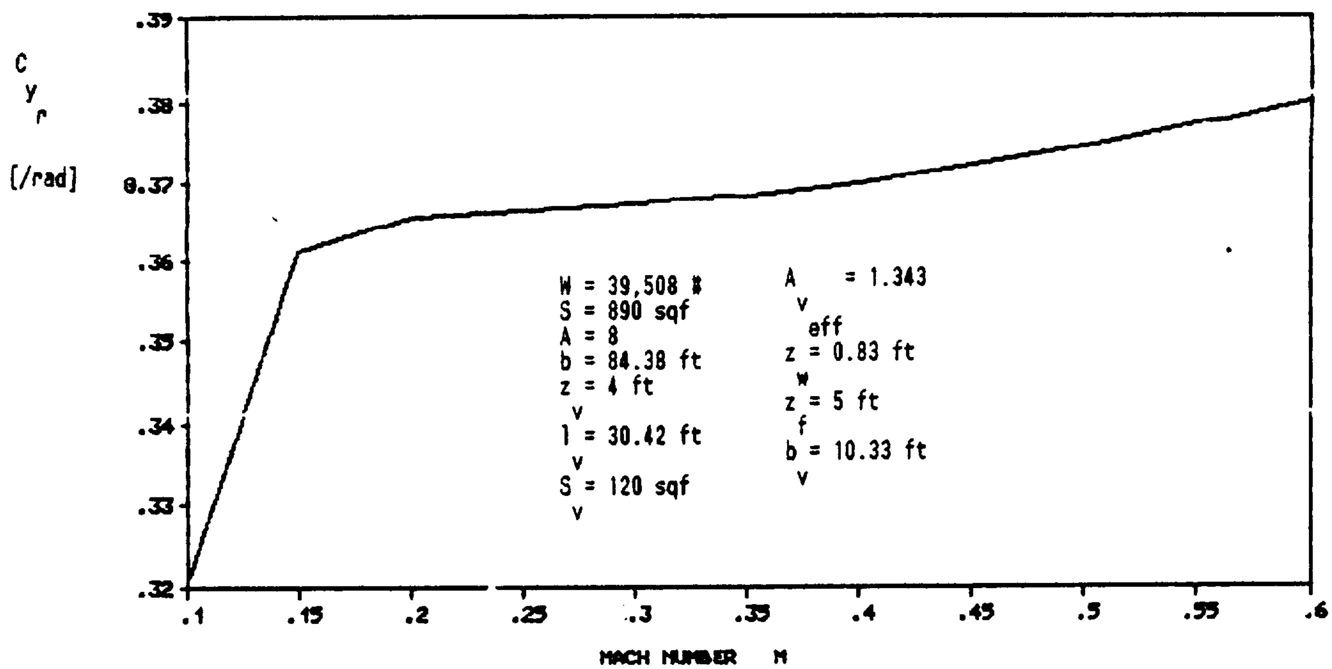

Figure 7.29 Variation of side force coefficient with yaw rate, variation with Mach number.

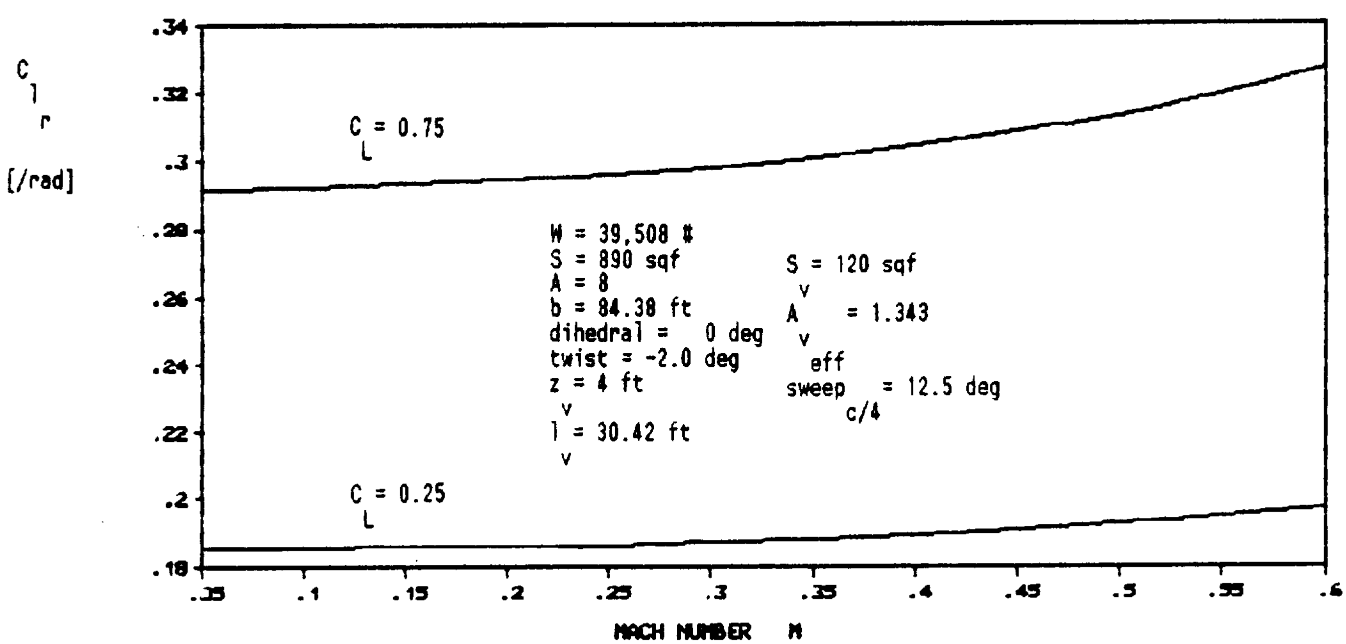

Figure 7.30 Variation of rolling moment coefficient with yaw rate, variation with Mach number.

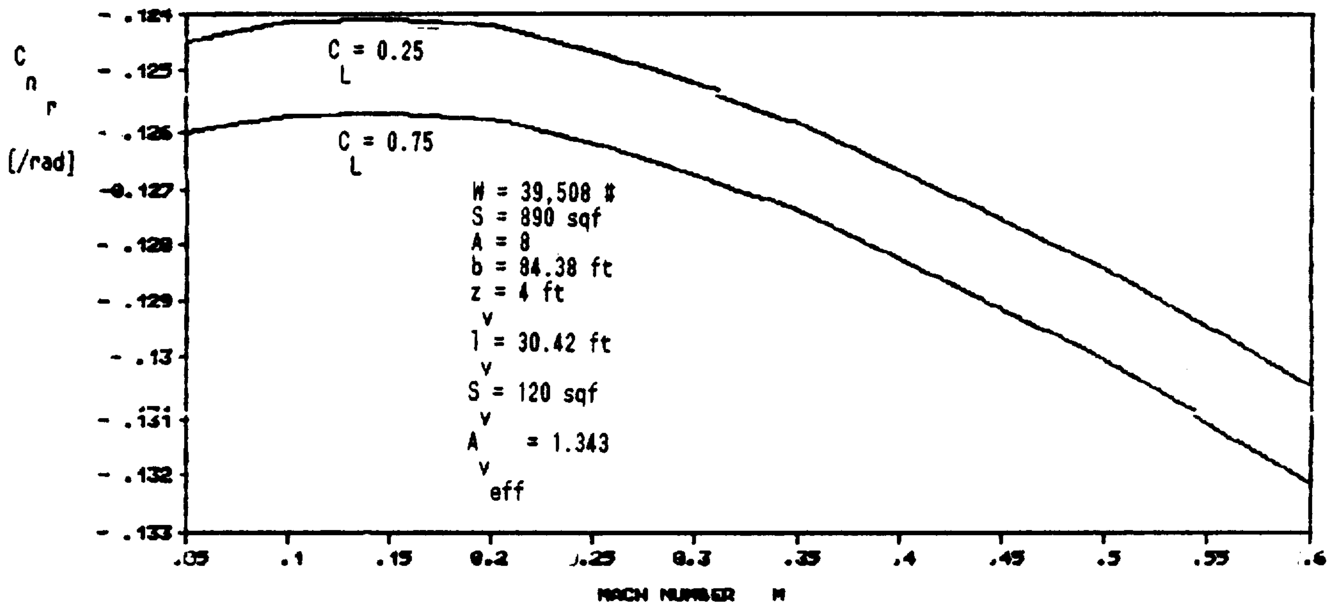

Figure 7.31 Variation of yawing moment coefficient with yaw rate, variation with Mach number.

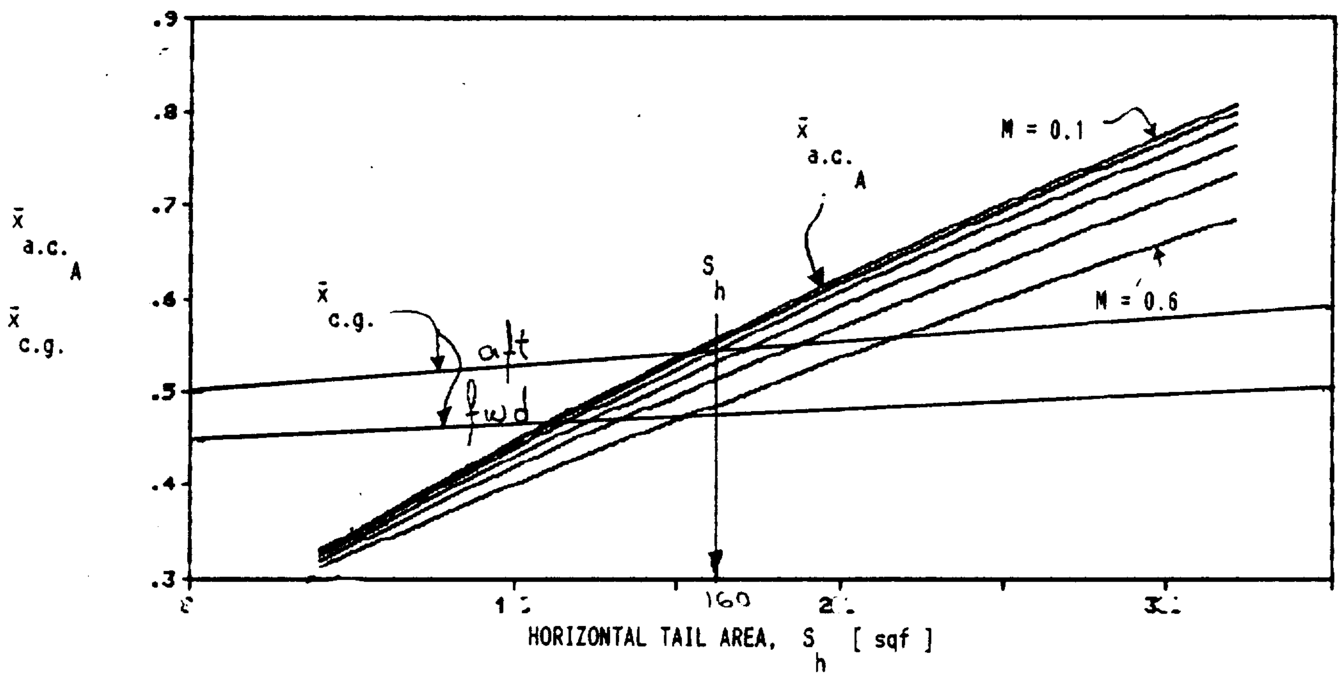

Figure 7.32 Longitudinal X-plot (i.e. static longitudinal stability), airplane aerodynamic center and center of gravity location variation with horizontal tail area.

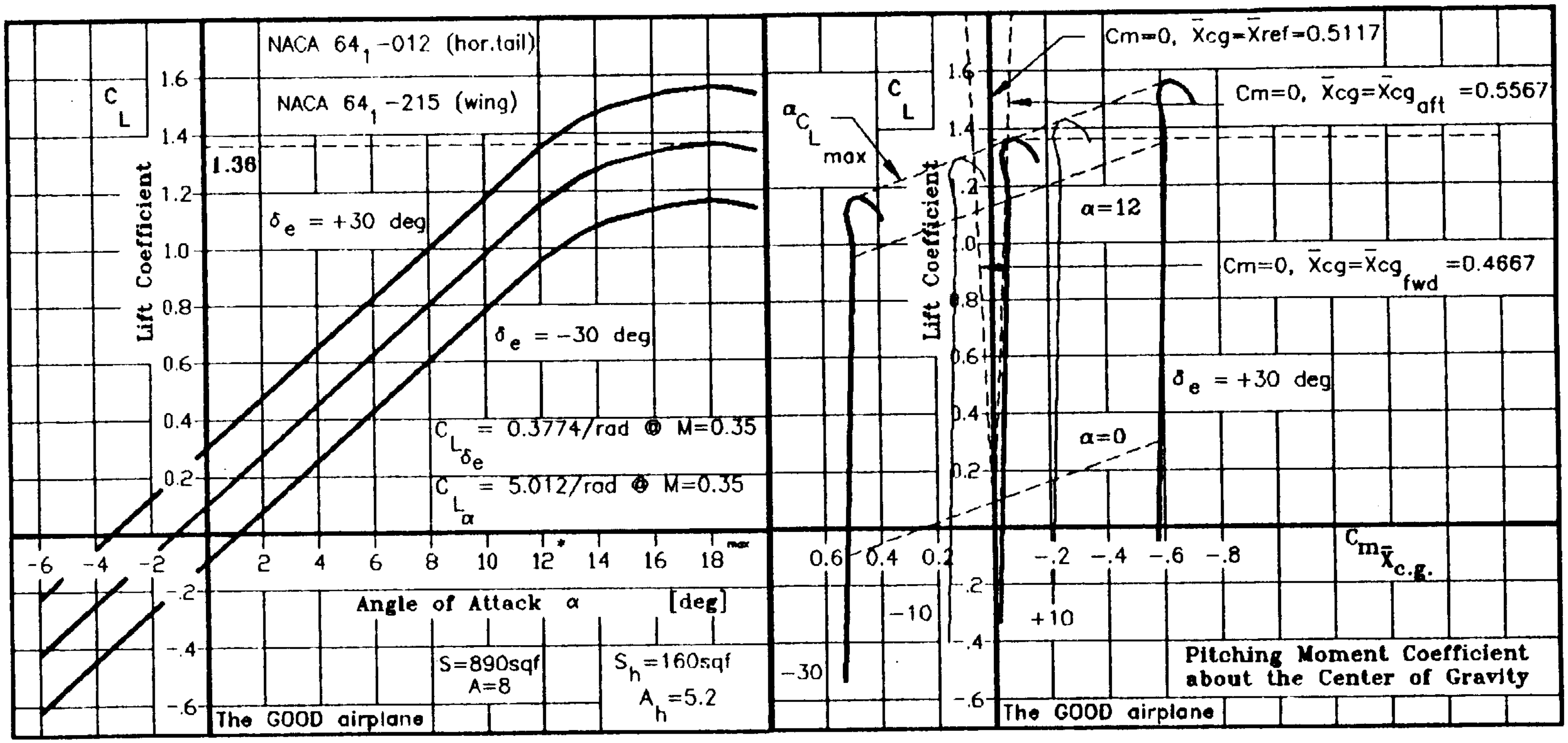

Figure 7.33 Trim diagram, pitching moment slope for the GOOD airplane, about the center of gravity.

8. STRUCTURAL DESIGN OF THE GOOD, BAD, AND UGLY AIRCRAFT

This chapter presents the preliminary materials selection and the structural design for the Good aircraft. The work presented here was done for the Good airplane only because not enough time was available to work on all three aircraft. Because of the high degree of commonality between the Good, Bad, and Ugly, the structural design for the Bad and Ugly would be similar to what is shown here for the Good.

8.1 Materials Selection

The Good, Bad, and Ugly airplanes would not be built until the mid 1990's, so it is assumed that advanced materials will be more cost-effective then than they are now. Therefore, these aircraft are designed to make extensive use of advanced materials. The materials distribution in the Good, Bad, and Ugly aircraft is as follows:

* ARALL (Aramid - Aluminum Laminate) is an advanced metal material that can be formed into sheets (Reference 18). Its laminate structure prevents its use in milled or extruded structures, but works well in highly stressed skins. Therefore, ARALL is used for most fuselage skins, wing and stabilized torque box skins, and tail boom skins. ARALL is also used in the inlets.

* 2024 Aluminum is inexpensive. In lightly loaded members, the cost of an advanced material is not likely to justify the small drop in weight. Therefore, 2024 Aluminum is used in lightly loaded internal frames and longerons, wing and empennage leading edge skins and ribs, and for miscellaneous lightly loaded structural components. Using 2024 Aluminum in wing and empennage leading edges has the additional advantage of making them easier to repair after a bird strike than if they had been made of advanced materials.

* Metal Matrix Materials are metals that have non-metallic fibers suspended throughout the material. A metal matrix material is essentially a composite material with a metal used to perform the role normally given to a resin. These materials can be treated like a normal metal, but are much stronger and more heat resistant. One such material is made by DURAL, and is composed of Aluminum with 20% by weight Silicon Dioxide. According to Reference 19, this material is 50% stiffer than the parent aluminum and yields components that are 25% lighter than similar components made with straight aluminum. For the Good, Bad, and Ugly airplanes, this material will be based on 2024 aluminum. Reference 19 also indicates that this material can be made more at a lower cost than other advanced materials because it does not require special manufacturing procedures. Therefore, this material will be used in the wing spars, stringers, and ribs aft of the front spar, and in all heavily loaded fuselage, boom, and empennage structure.

* Carbon Fiber Composite materials are stiff and have high strength/weight ratios, but they are expensive and difficult to repair. Therefore, nonmetallic composites will be limited to control surfaces, access panels, fairings, and landing gear doors.

* Aluminum Honeycomb is used in the leading edge snags on the Good airplane, and in the portion of the vertical tail that is immediately below the rudder. This provides crushable material to protect the rudder if the pilot over rotates on take off or landing.

* Titanium is used in engine support frames, firewalls, and heat shields. Titanium is also used as blast shields around the portion of the wheel well that is close to the tires, and is used for armor plating the cockpit tub.

* Steel is used for the landing gear struts, braces, and mounts, and for all control cables.

* Fiberglass is used in wing tips, vertical tail/horizontal tail joint fairings, and for the radome.

* The tires and hoses are rubber.

* The canopy is plexiglass.

Figure 8.1 shows the material distribution of the aircraft.

8.2. Structural Layout and Design of the Good, Bad, and Ugly Aircraft

This chapter presents structural layout of the Good, Bad, and Ugly aircraft. The structural design of these aircraft is divided into three parts: 1) the wing, 2) the fuselage, and 3) the booms and empennage.

8.2.1 Structural Design of the Wing

The wing used in the Good, Bad, and Ugly aircraft is designed so that the outer section of the good wing forms the entire Ugly wing, and the outer two sections of the Good wing forms the entire Bad wing. According to Reference 7, the wing uses a NACA 64A-215 airfoil. The initial structural layout for the wings was performed using the methods of Reference 17.

The wing was designed with synergism in mind. The commonality demanded by the three aircraft's use of the wing eliminates much of the wing's potential for synergistic weight savings. The outer ejector rack attachment point for the good aircraft was mounted to the outer joint rib of the Bad boom mount. The need to remove portions of the flaps to allow placement of booms and landing gear, and to allow mounting of wing segments to various aircraft, required the flaps to be

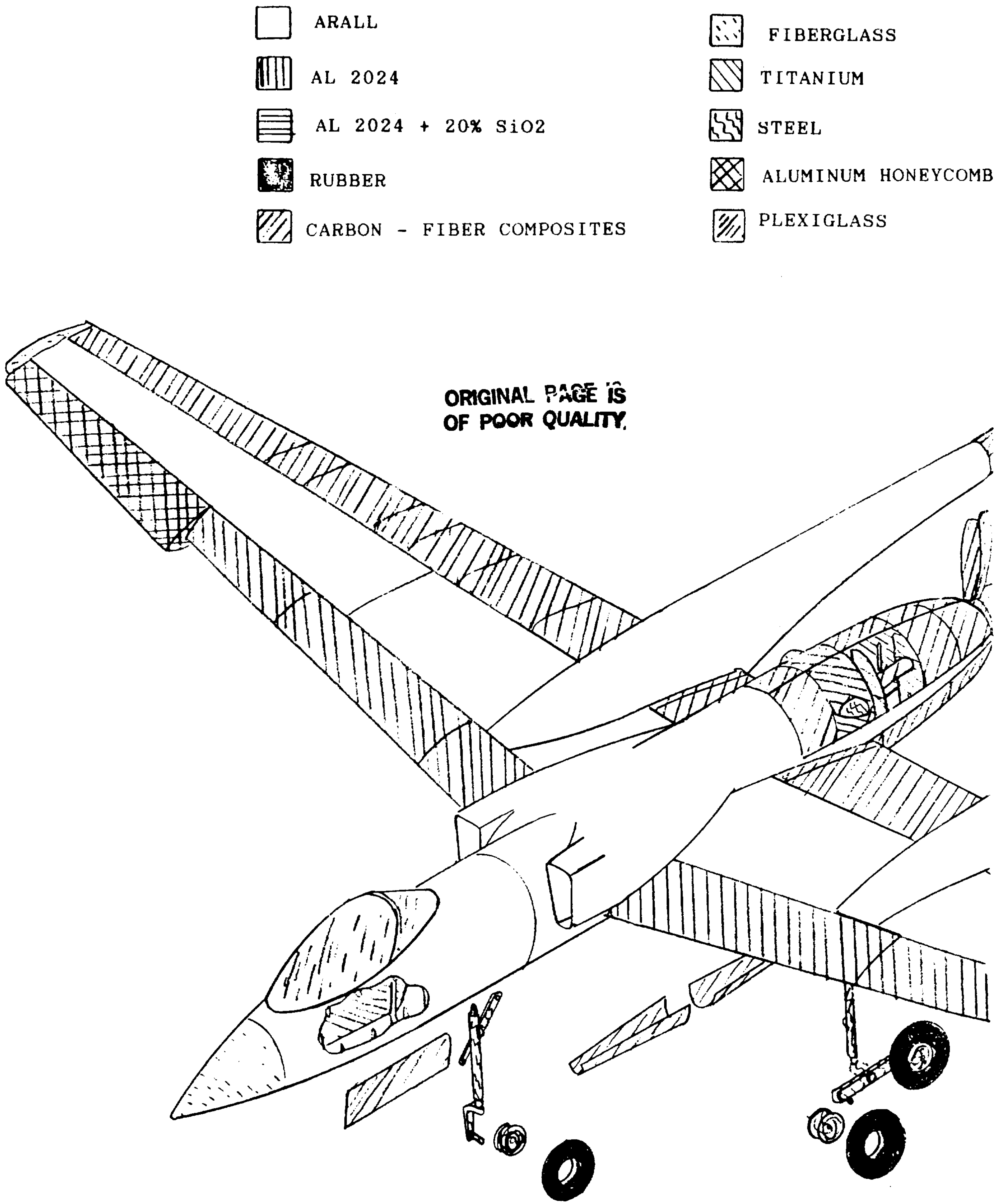

Figure 8.1: Material distribution f
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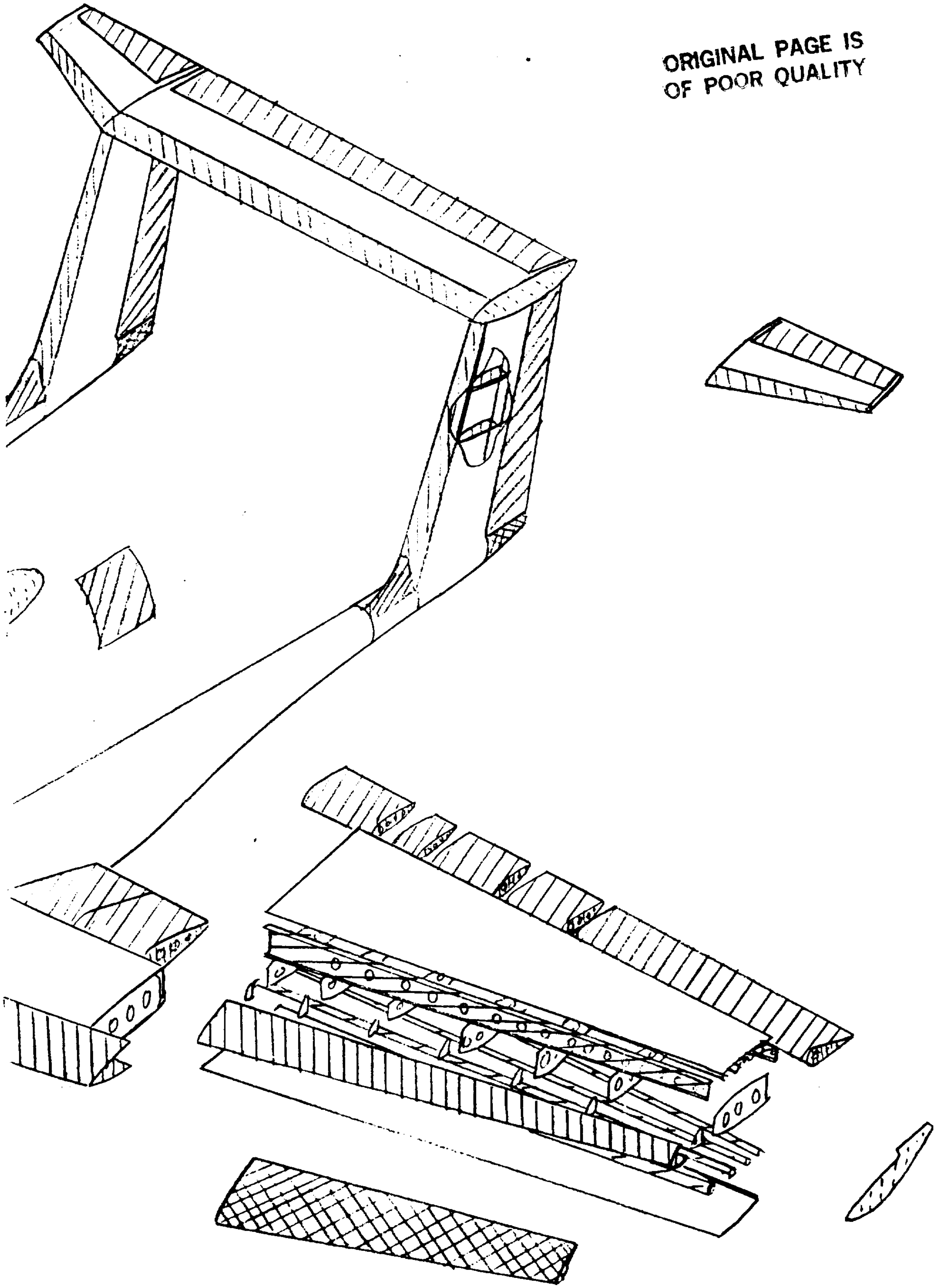

or the Good, Bad, and Ugly
ne shown.)

segmented. This is actually a benefit because high aspect ratio wings are often subject to sufficient flexure to cause flap binding if the flaps are not segmented.

Using Reference 17 as a guide, a rib spacing of 21 inches was estimated. No stringer spacing was estimated, but a spacing of 15 inches is being assumed for the detail drawings. The Good wing has a very small taper ratio. To prevent tip stall, leading edge snags are bolted on to the outer wings section. These snags have their own structure, and are removed when the wing is used on the Bad or Ugly airplanes. Figure 8.2 presents the overall wing structural arrangement.

8.2.2 Fuselage Structural Layout

The fuselage was laid out using the step by step procedure of Reference 17. The ejection seat is mounted to the nose gear, and the gun is suspended from the barrel support ring and from the firing block. The gun is mounted to the ammo drum mount as well as to frames of its own. The engines, gear boxes, and propellers are mounted to thickened frames. The forward engine mount also functions as one of the wing torque box mounts. Titanium firewalls are located between the engines and forward of the front engine mounts. The exhaust ports are surrounded by a titanium heat shield. The ammo drum is mounted to thickened frames. The radar is mounted to a bulkhead forward of the cockpit. The major cutouts in the fuselage are the nose wheel well opening and the cockpit opening. These are strengthened by using stiffened stringers and frames around the wheel well and thickened skin around the canopy.

The forward fuselage was designed to be common between the aircraft from the ammo drum mount forward. The gun fairing is common to all aircraft and the aft fuselage is common on the Good and Bad aircraft from the forward engine mount aft. The lower portion of the first two frames will need to be removed to make room for the torque box on the bad aircraft, however. The aft fuselage of the Ugly airplane must house only one engine, and thus cannot be made common with the other airplanes. In all three airplanes, the entire upper and lower aft fuselage skins are removable for engine access. The main loads of this section are carried by spars in the center of each side of the aft fuselage, and these spars bolt to the top of the wing torque box at several wing spar locations.

Synergism can be improved by moving the forward ammo drum mount two inches aft. This allows the aft ammo drum mount to serve as the forward torque bow mount on the Good aircraft. This was assumed in the drawings. The spacings chosen for the minor frames and longerons are:

* Frames: 14 inches
* Longerons: 10 inches
* Structural depth: 2 inches

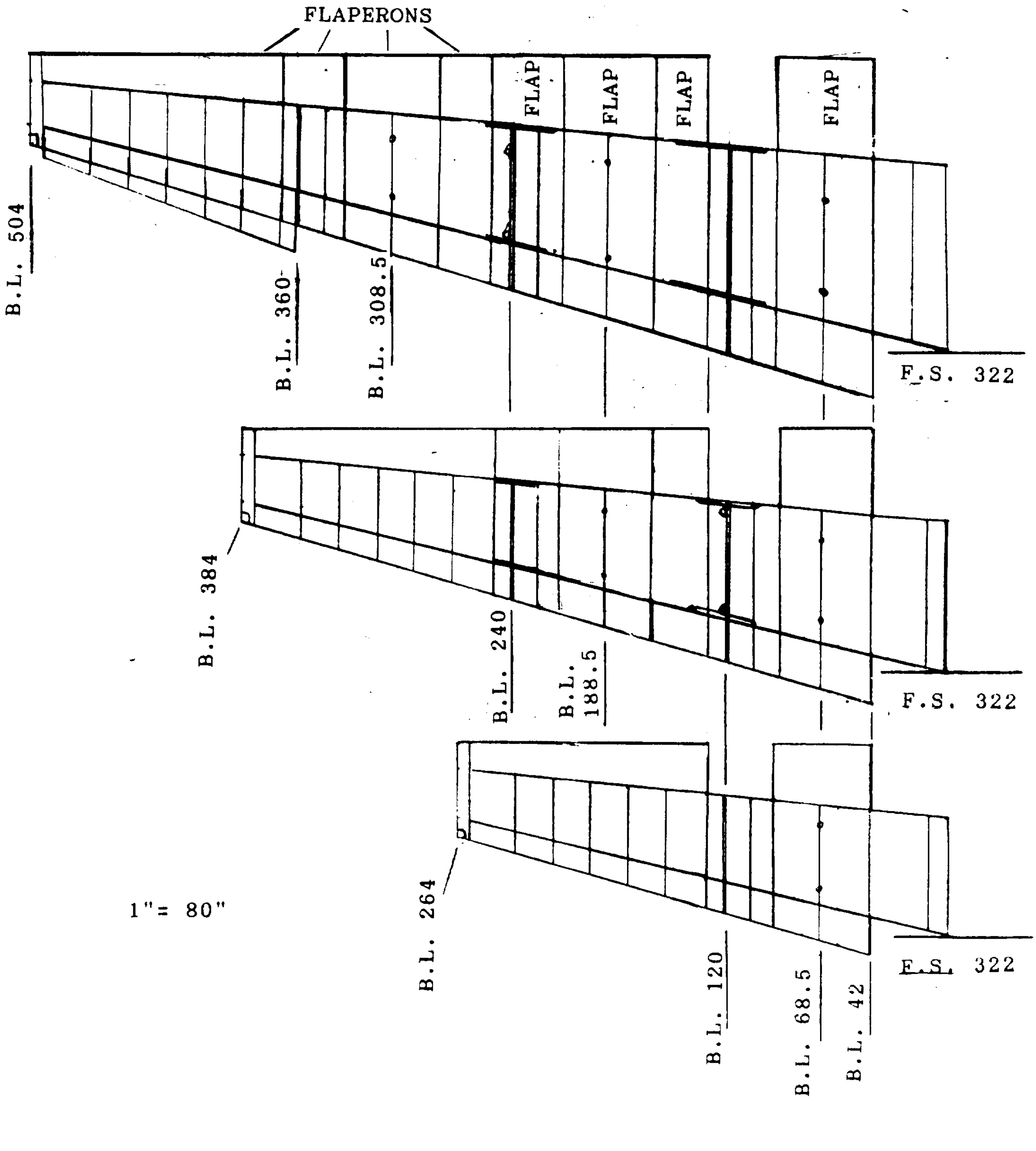

Figure 8.2: Wing structural layout for the Good, Bad, and Ugly aircraft.

According to Reference 17, these numbers are typical for fighter aircraft. Figures 8.3, 8.4, and 8.5 present the fuselage structural layouts of the three aircraft.

8.2.3 Boom and Empennage Structural Layout

The boom and empennage structure were laid out in the same manner as the wing and fuselage. The landing gear is attached to the wing and retracts into the boom, so the only major attachment points on the boom are the landing gear actuator/drag brace, the uplock, and the empennage attachment. The structure of the boom is based on four heavy longitudinal members. Two of these members run along the top of the boom. The outboard member follows B.L.120, but the inboard member runs diagonally, allowing for the taper of the boom. The other two members run flush along the sides of the boom at the level of the rear spar of the wing. The frames are spaced 14 inches apart, and are suspended from these 4 beams. Longerons are spaced 10 inches apart. A cut out is provided for main gear retraction, and the frames are shaped to create a P shaped box over the gear. On the Good and Bad aircraft, the empennage bolts on at F.S. 686.8, and on the Ugly aircraft at F.S. 532.8. The Good and Bad aircraft use the same booms, but the Ugly airplane has its own booms.

The empennage has spars at 20 and 69.5% chord, and the bottom of the vertical tail is tailored to allow for 13 degrees of rotation clearance. Fifteen degrees is standard, but this could not be achieved with the existing gear. The main gear should be lengthened if this is a problem. Sufficient room was left in the boom for growth in this case. The top of the rudder was angled to allow for elevator deflection when the rudders are deflected. The four beams used in the booms were extended into the empennage structure, and are attached by bolts to the boom structure. Synergism is obtained in the following areas:

* The actuator/drag brace is mounted between the boom spine beams.
* The spars on the vertical and horizontal tails are connected.

The rudder is protected from over rotation by a section of crushable structure below the upper boom beams beneath the rudder. Figures 8.6 and 8.7 show the layout of the boom structure.

8.3 Detailed Structural Layout of the Landing Gear and Boom Attachments, Nose Section, and Horizontal Tail Extensions

This section presents the detailed structural layout of several sections of the aircraft. None of the members shown in this section have been sized, and therefore the thicknesses shown in the drawings are not to scale.

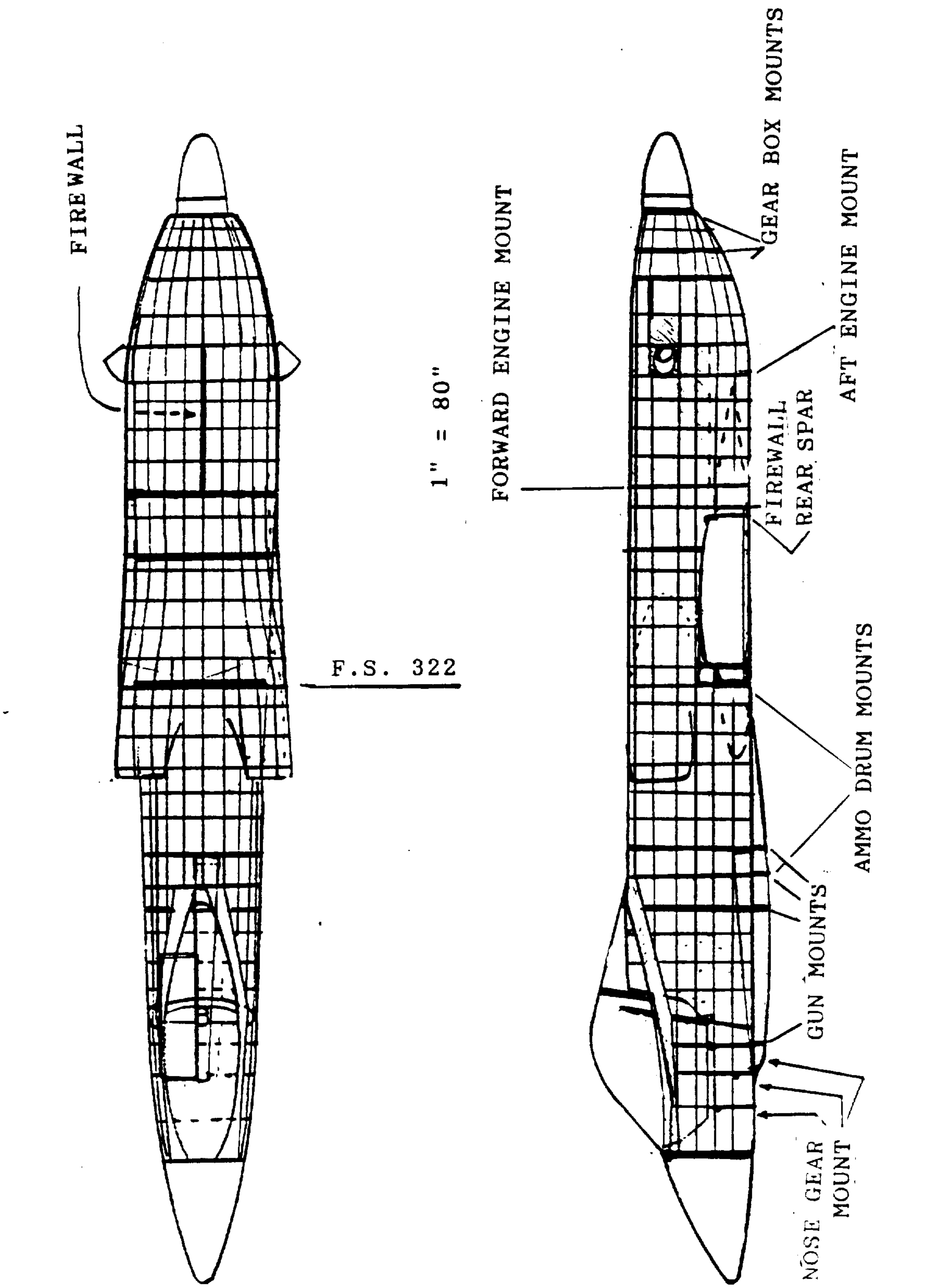

Figure 8.3: Fuselage structural layout for the Good airplane.

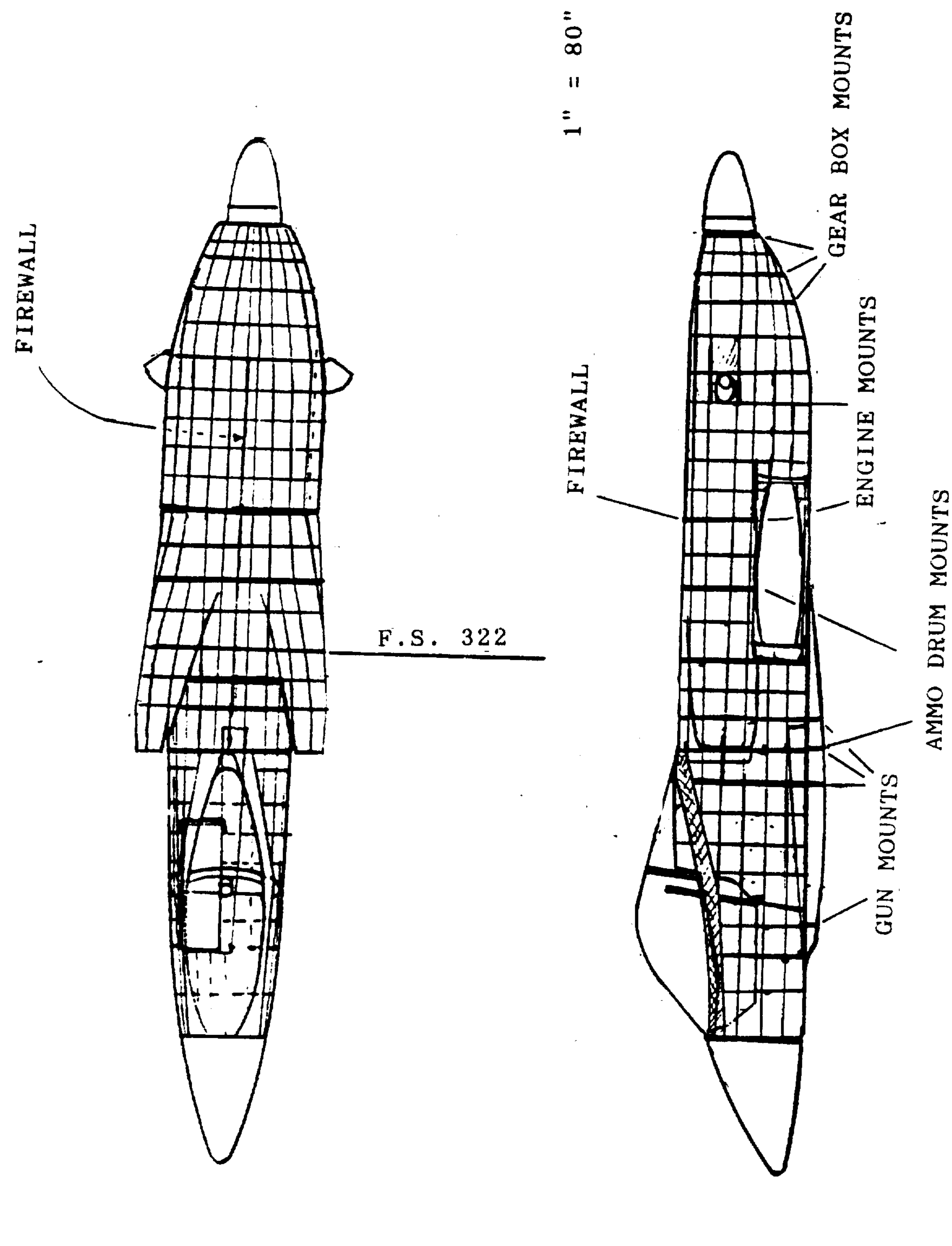

Figure 8.4: Fuselage structural layout for the Bad aircraft.

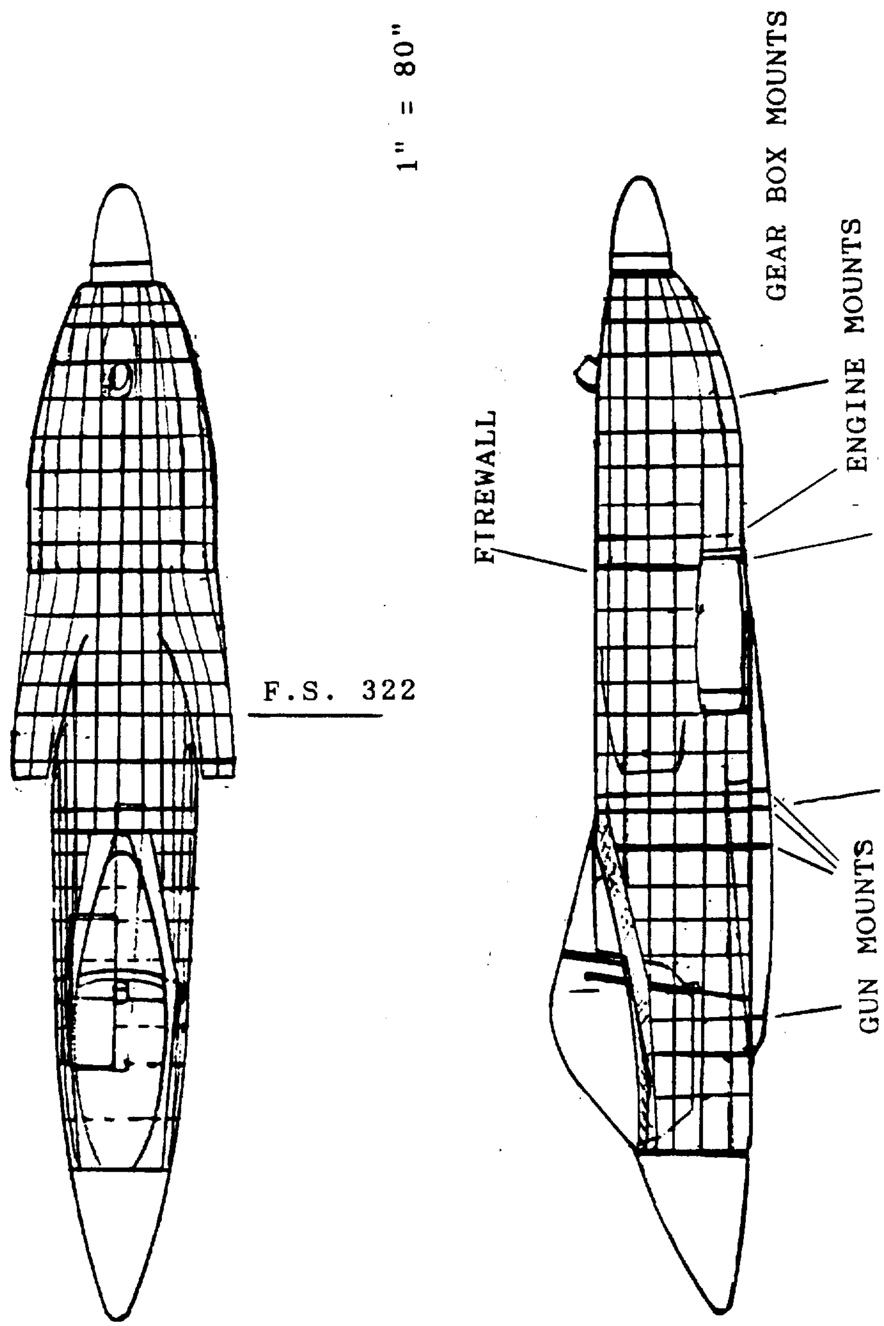

Figure 8.5: Fuselage structural layout for the Ugly aircraft.

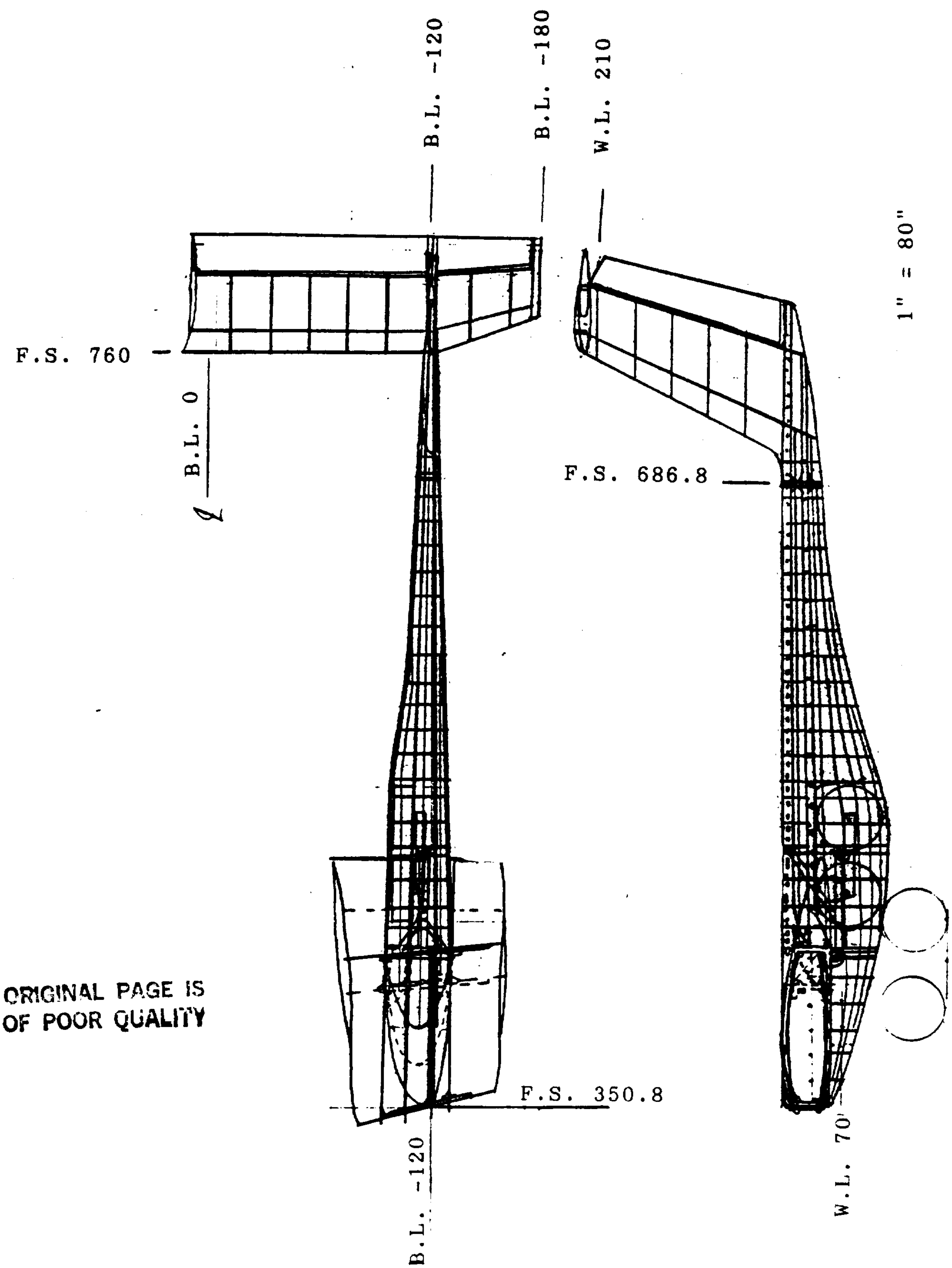

Figure 8.6: Boom and empennage structural layout for the Good and Bad aircraft.

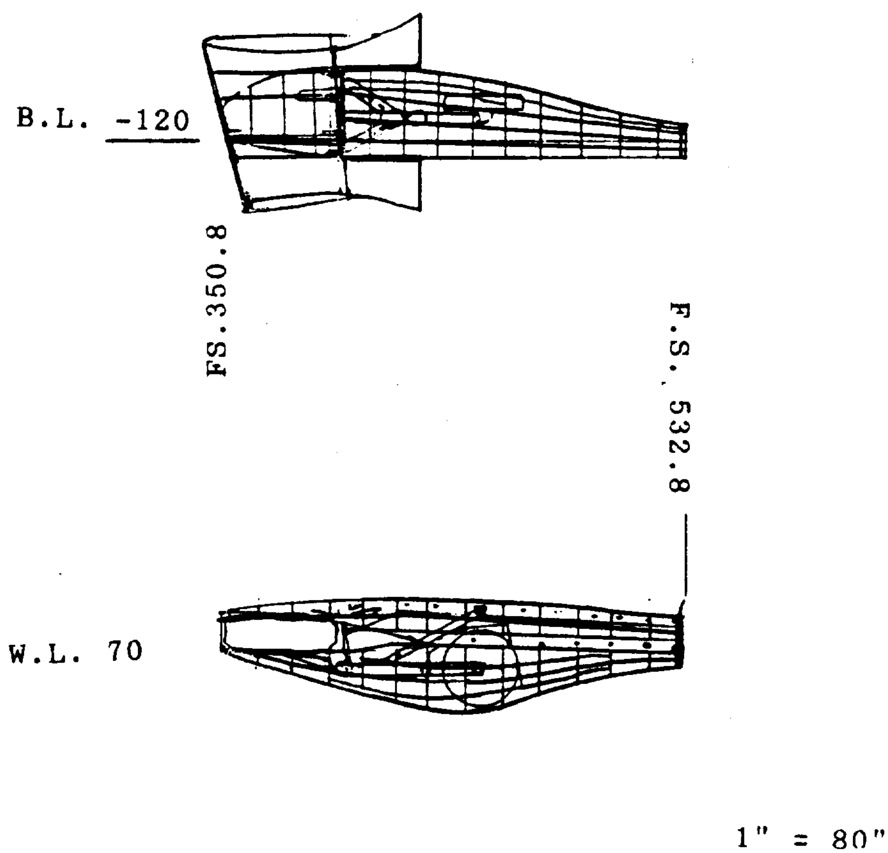

Figure 8.7: Structural layout of the booms of the Ugly airplane.

8.3.1 Boom and Main Gear Attachment

The landing gear is attached to the wing and retracts into the boom, so the only major attachment points on the boom are the landing gear actuator/drag brace, the uplock, and the empennage attachment. The structure of the boom is based on four heavy longitudinal members. Two of these members run along the top of the boom. The outboard member follows B.L.120, but the inboard member runs diagonally, allowing for the taper of the boom. The other two members run flush along the sides of the boom at the level of the rear spar of the wing. The frames are suspended from these 4 beams. A cut-out is provided for main gear retraction, and the frames are shaped to create a P shaped box over the gear. This is similar to the arrangement suggested in Reference 7. The suggestion of placing the gear beside the boom could not be followed exactly because that design did not allow for structural depth or landing gear strut thickness.

For the Good and Bad aircraft, the boom was designed to fit the wing of the Good aircraft. This allows one boom to be used for both aircraft. This also requires that adapters be designed that will account for the smaller wing of the Bad aircraft. Figures 8.8a-e show the layout design of boom and main gear attachments for the Good and Bad aircraft.

The boom and main gear attachment design for the Good and Bad aircraft has the following characteristics:

* The main boom structure attaches to the wing at four points:
  1. The side braces bolt onto the rear spar. The bolts for this attachment point pass through the rear spar, the splice plate, the landing gear mounting bracket, and the side brace flange. These bolts are in shear for vertical loads, and in tension for longitudinal loads. Alternate designs should be considered that will place the bolts in shear for all loads. The current design was developed so that there will be no projections aft of the rear spar when the boom is removed. This simplifies the conversion of the wing for use on different aircraft.
  2. The outboard upper brace forms a "Y" shape at the aft end of the wing. This piece bolts around the ribs at the wing segment joint located at B.L.120. At the wing segment joint, the standard ribs are replaced by ribs that are extended above the upper surface of the wing, thus providing an attachment surface for the brace. The attachment bolts are in shear for both vertical and longitudinal loads.

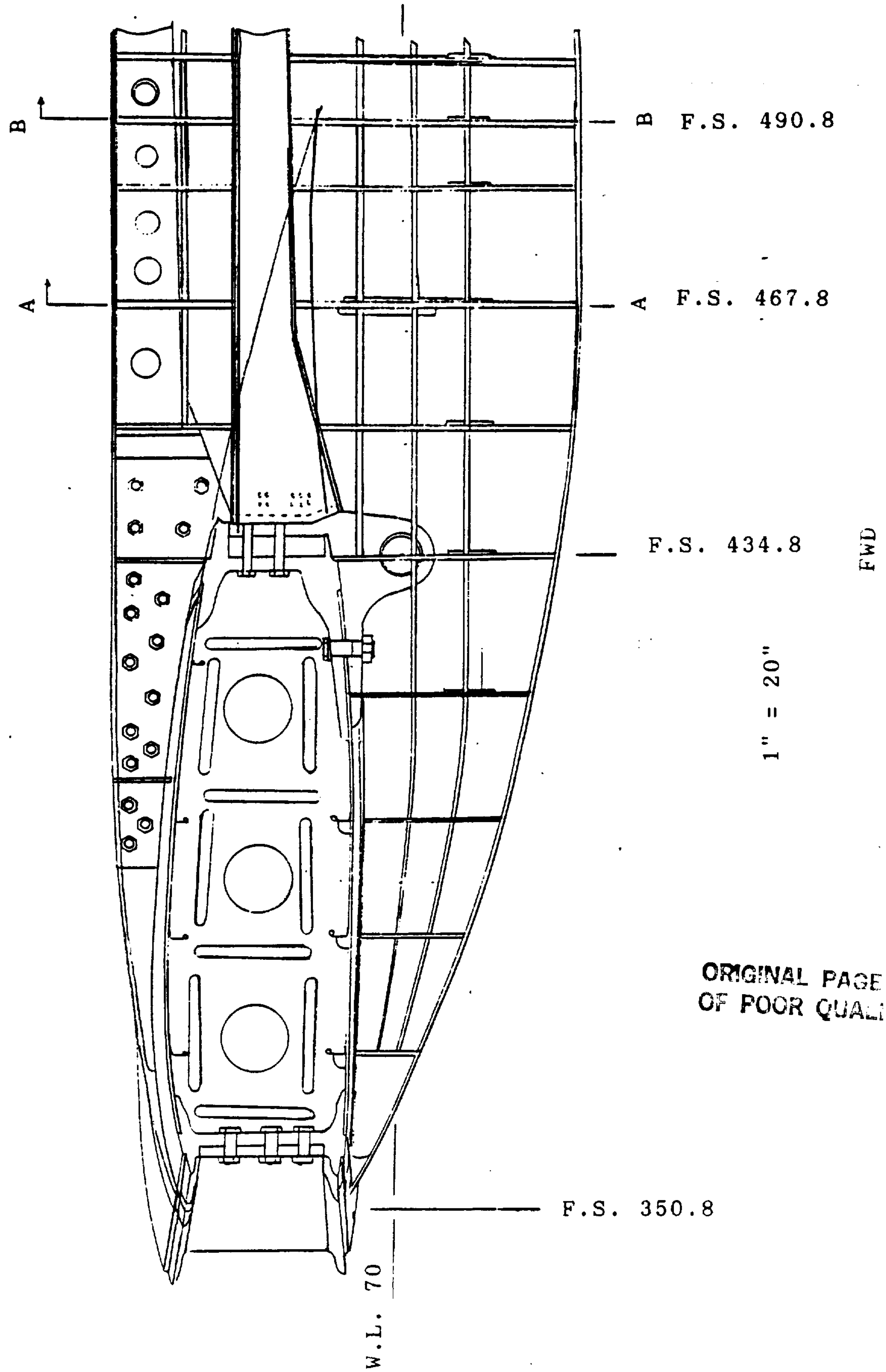

Figure 8.8a: Boom and main gear attachment for the Good airplane.(Side view)

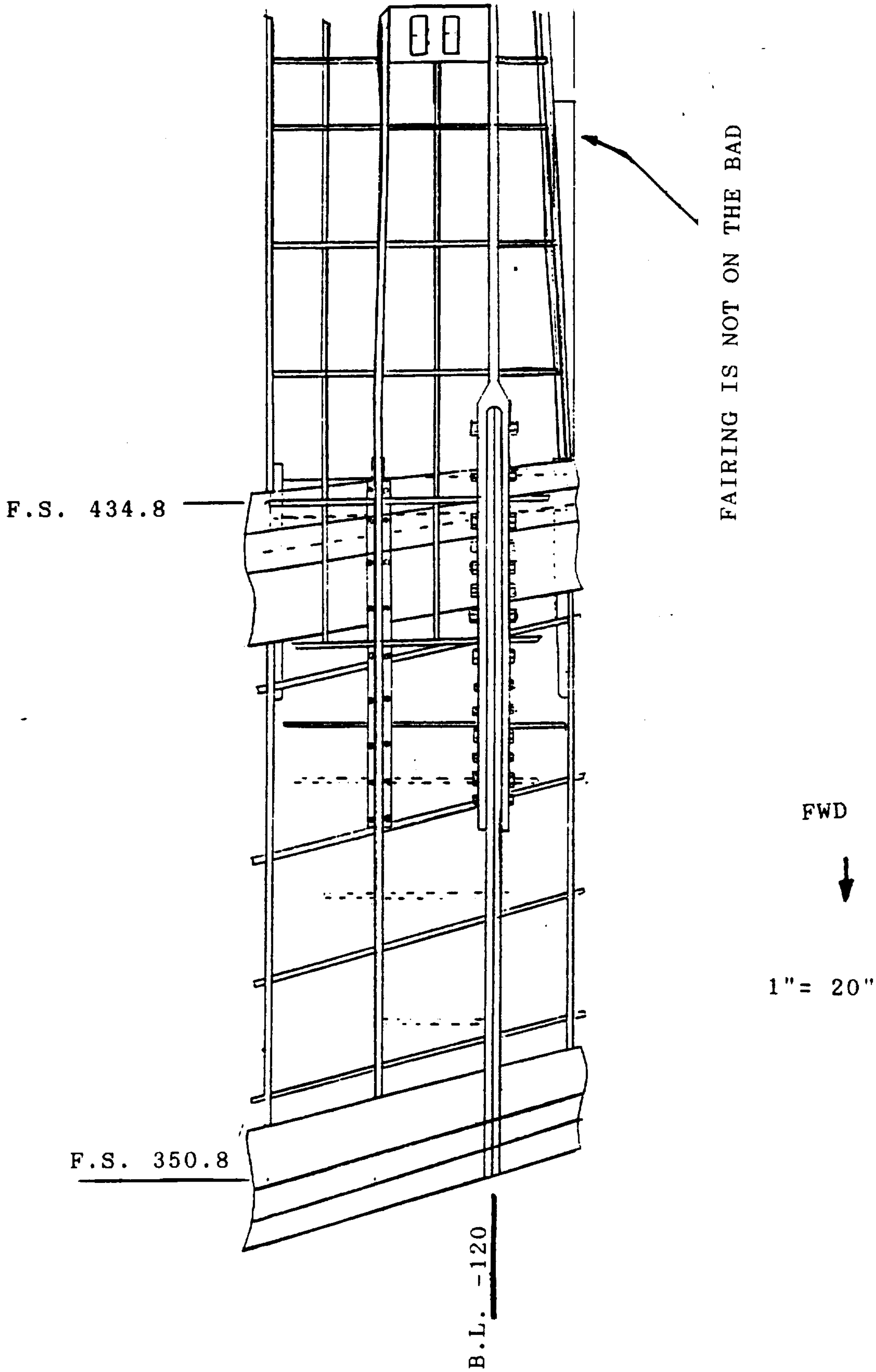

Figure 8.8b: Boom and main gear attachment for the Good airplane.(Top view)

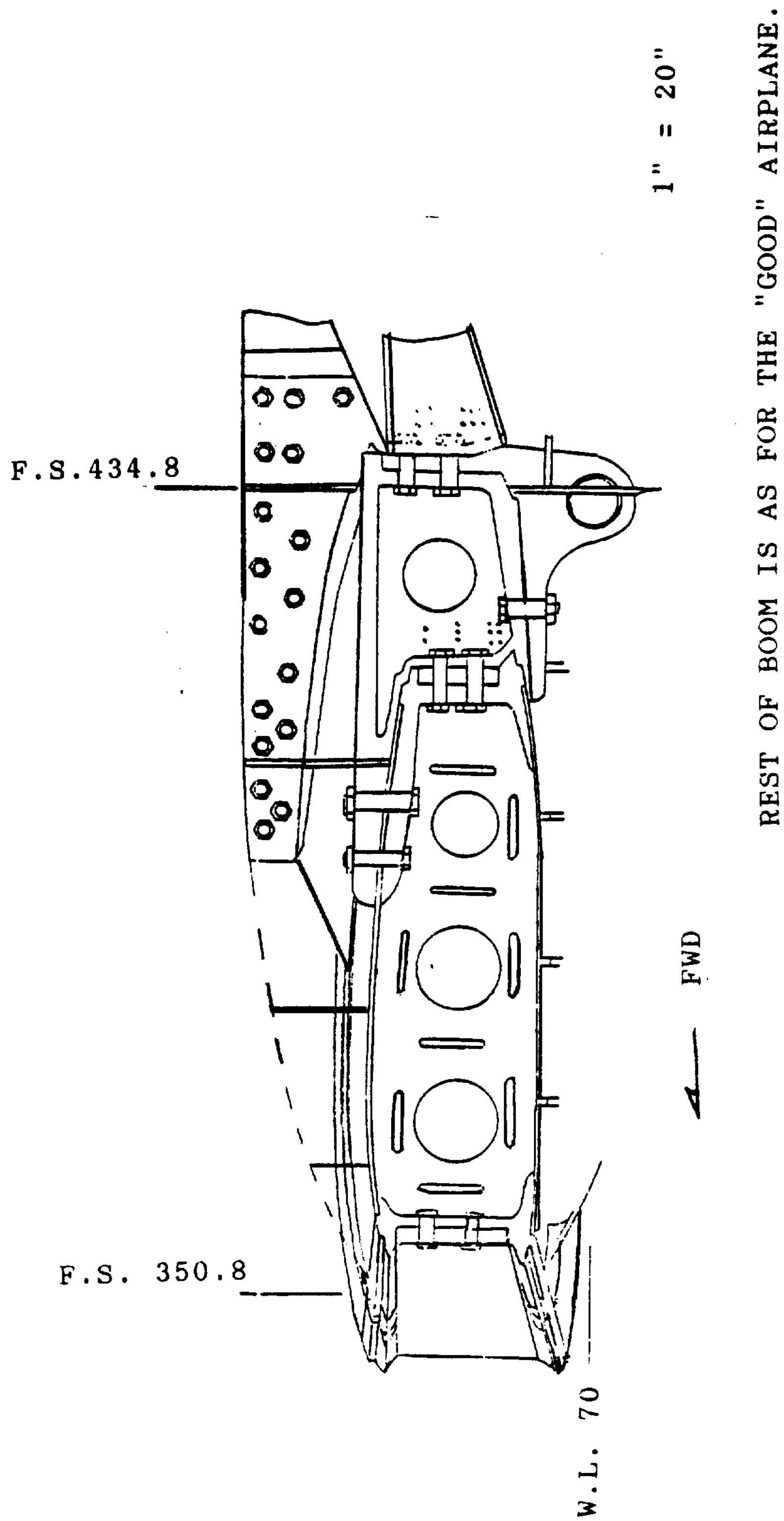

Figure 8.8c: Boom and main gear attachment for the Bad airplane.(Side view)

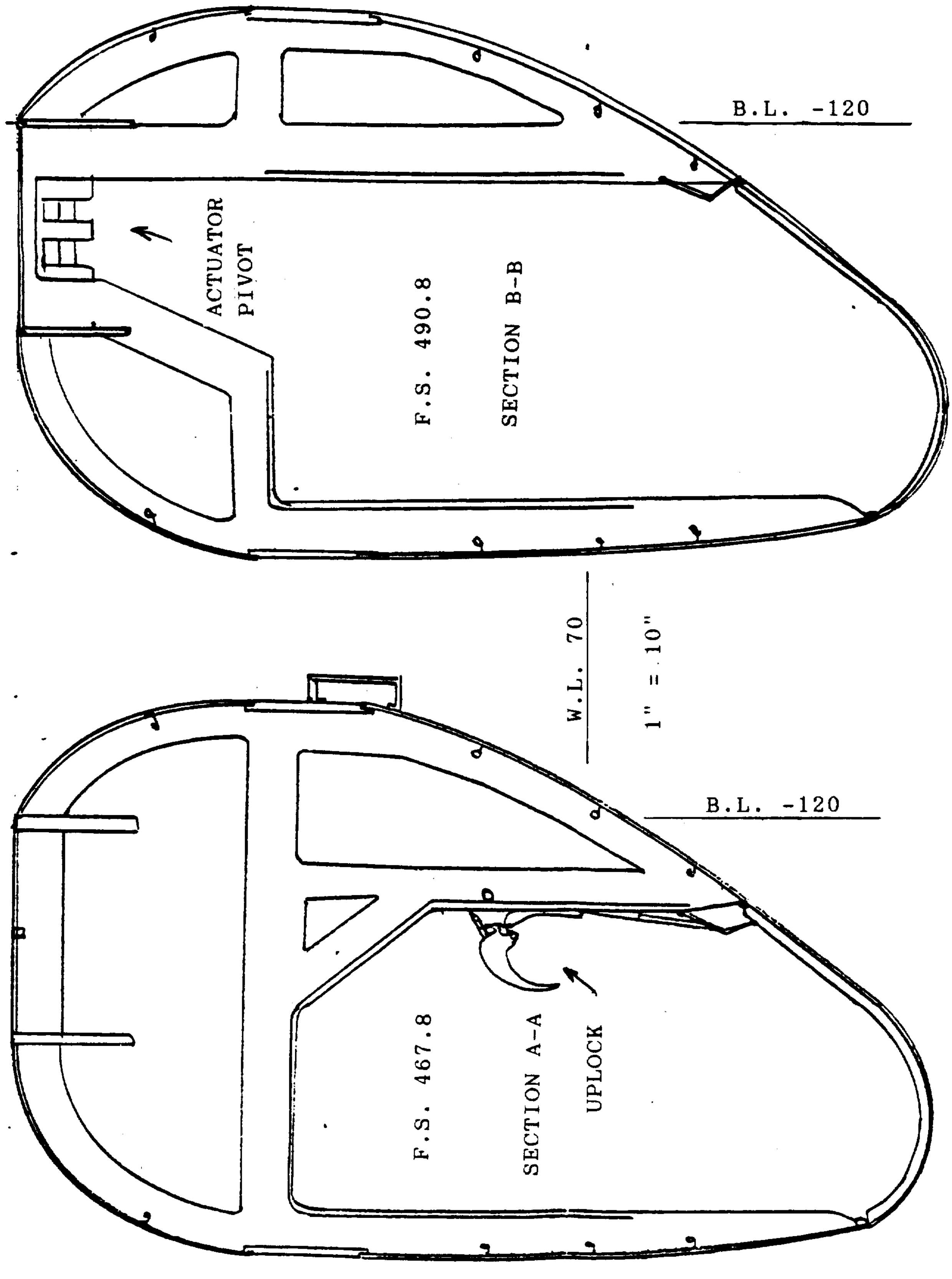

Figure 8.8d: Boom cross sections for the Good and Bad airplanes.

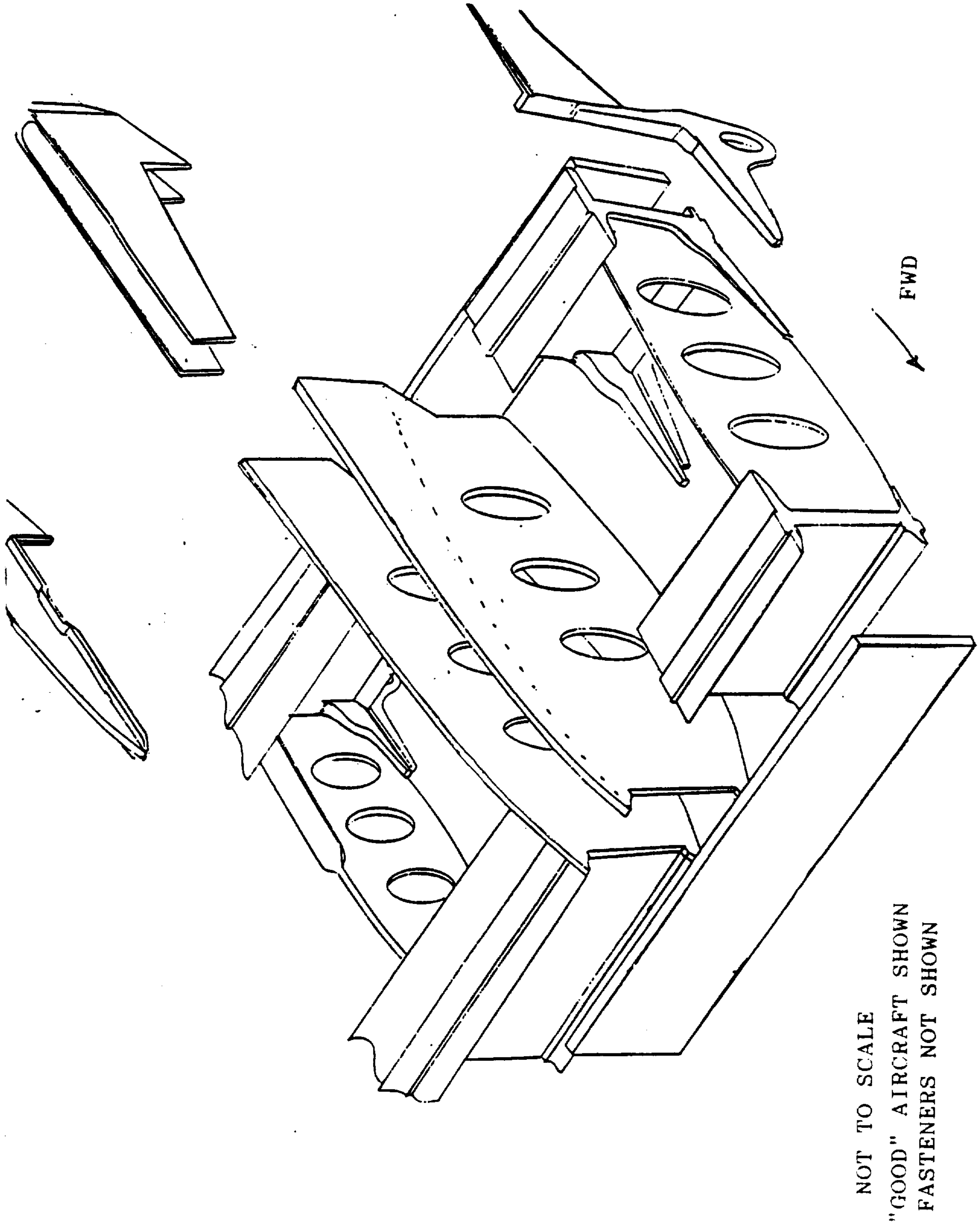

Figure 8.8e: Boom to wing attachment parts break down for the Good and Bad airplanes.

3. The inboard upper brace bolts directly onto a wing rib. This allows the same ribs to be used when the boom is attached and when it is not. This simplifies the conversion of the outer two sections of the Good wing for use as the Bad wing. However, the attachment bolts are in tension for vertical loads, so alternate arrangements should be studied.

* The landing gear mounts are "L" shaped, and bolt onto the rear spar and splice plate. When the outer sections of the Good wing are used on other aircraft, a gap is left behind the rear spar in the area previously occupied by the boom. This gap is filled with small sections of flap, so provision must be made for the attachment of skin to the spar caps. This creates some sharp corners in the landing gear mounting bracket, so alternate designs should be considered. The mounting bolts are in shear.

* The joint ribs on the Bad aircraft are extended aft and vertically to accept the Booms as for the Good airplane. The other three attachment points require adapter plates between the braces and the rear spar. Like the gear mounts, these adapter plates have many sharp corners, so alternate designs should be considered. These sharp corners exist for the same reasons as the corners on the landing gear mounts.

The booms used on the Ugly airplane are different from those used on the Good and Bad aircraft, so the boom and gear attachments for the Ugly airplane are treated separately. Figures 8.9a-d show the detailed structural layout for the boom and main gear attachments for the Ugly airplane. The boom used for the Ugly airplane is smaller than that used on the Good and Bad aircraft, so many of the components have slightly different shape than those used on the Good and Bad aircraft. Otherwise, the boom and main gear attachments for the Ugly aircraft differ from those of the Good and Bad aircraft in the following ways:

* Since there is no wing segment joint on the Ugly wing, no splice plates are used.

* Since the Ugly wing is not segmented, not segment joints exist for the booms to attach to. Thus the "Y" method used for the Good and Bad aircraft cannot be used. Instead, the direct bolt-on method used for the inboard upper braces on the Good aircraft is used for both upper braces on the Ugly airplane.

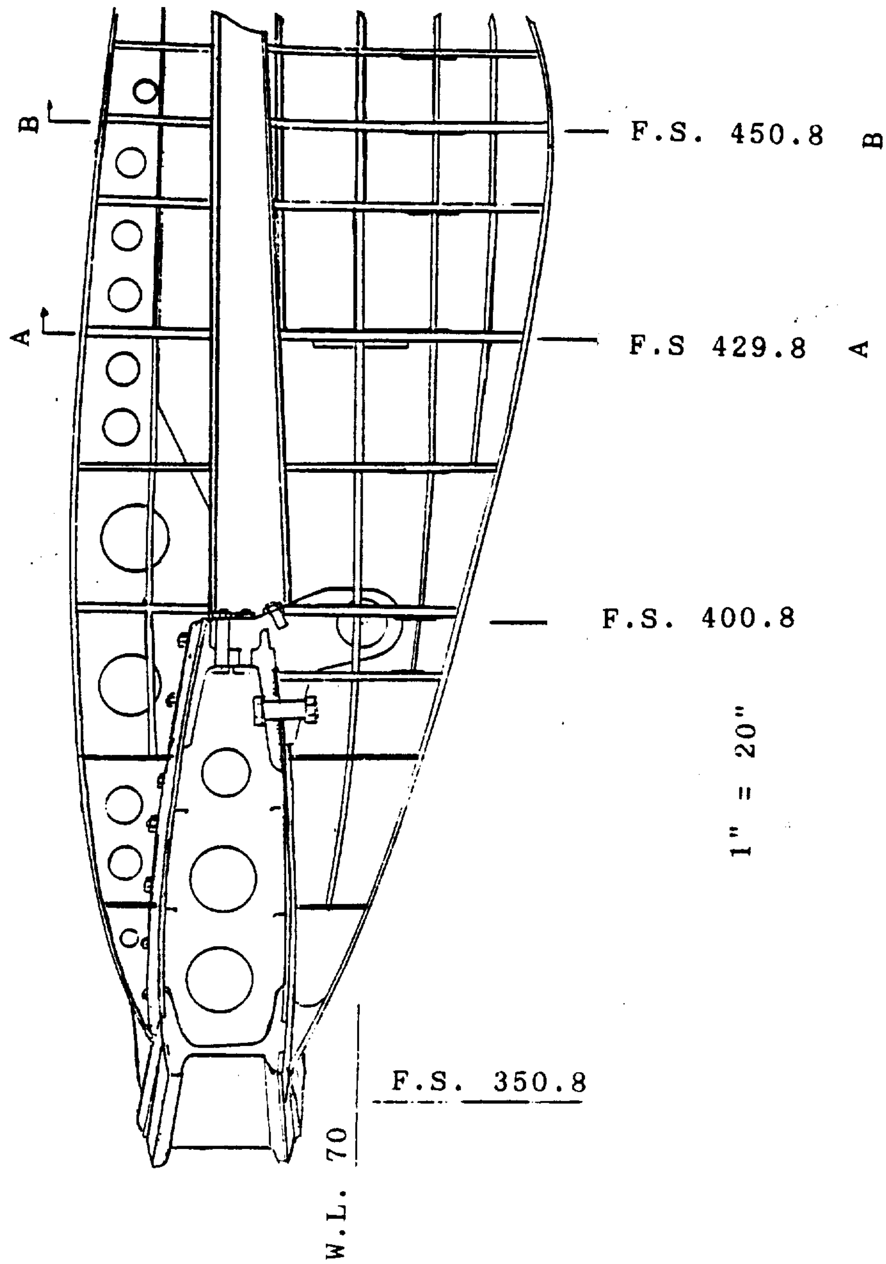

Figure 8.9a: Boom and main gear attachment for the Ugly airplane.(Side view)

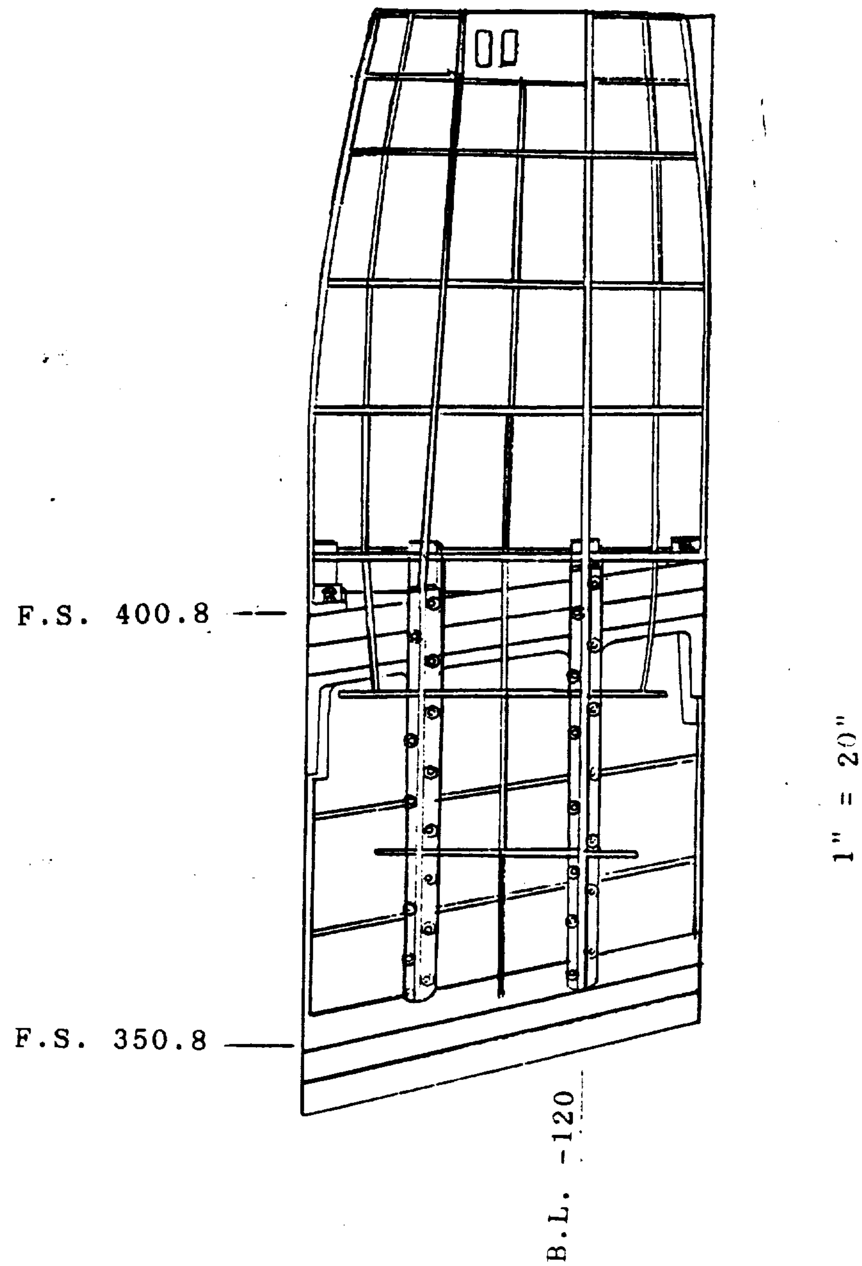

Figure 8.9b: Boom and main gear attachment for the Ugly airplane.(Top view)

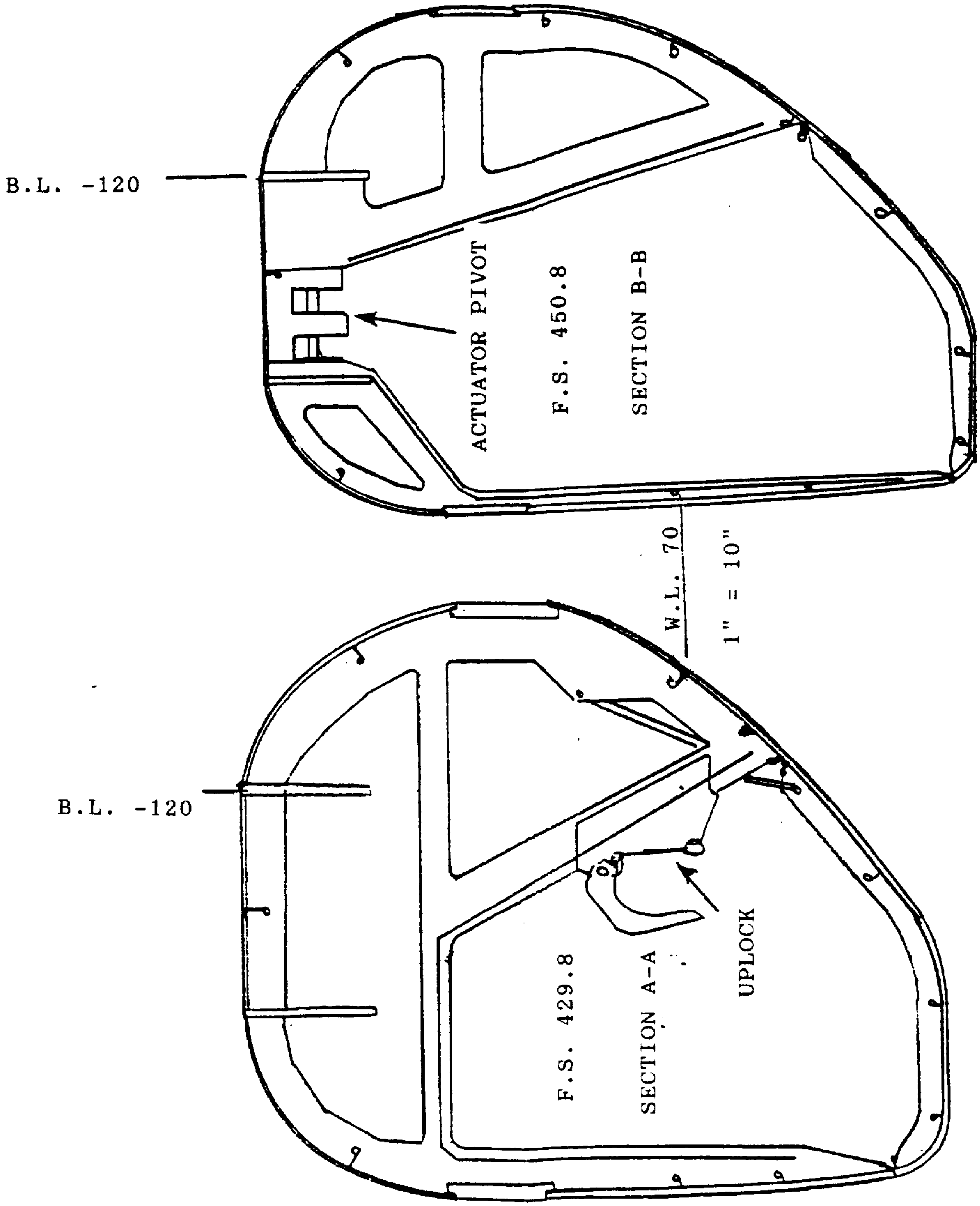

Figure 8.9c: Boom cross sections for the Ugly airplane.

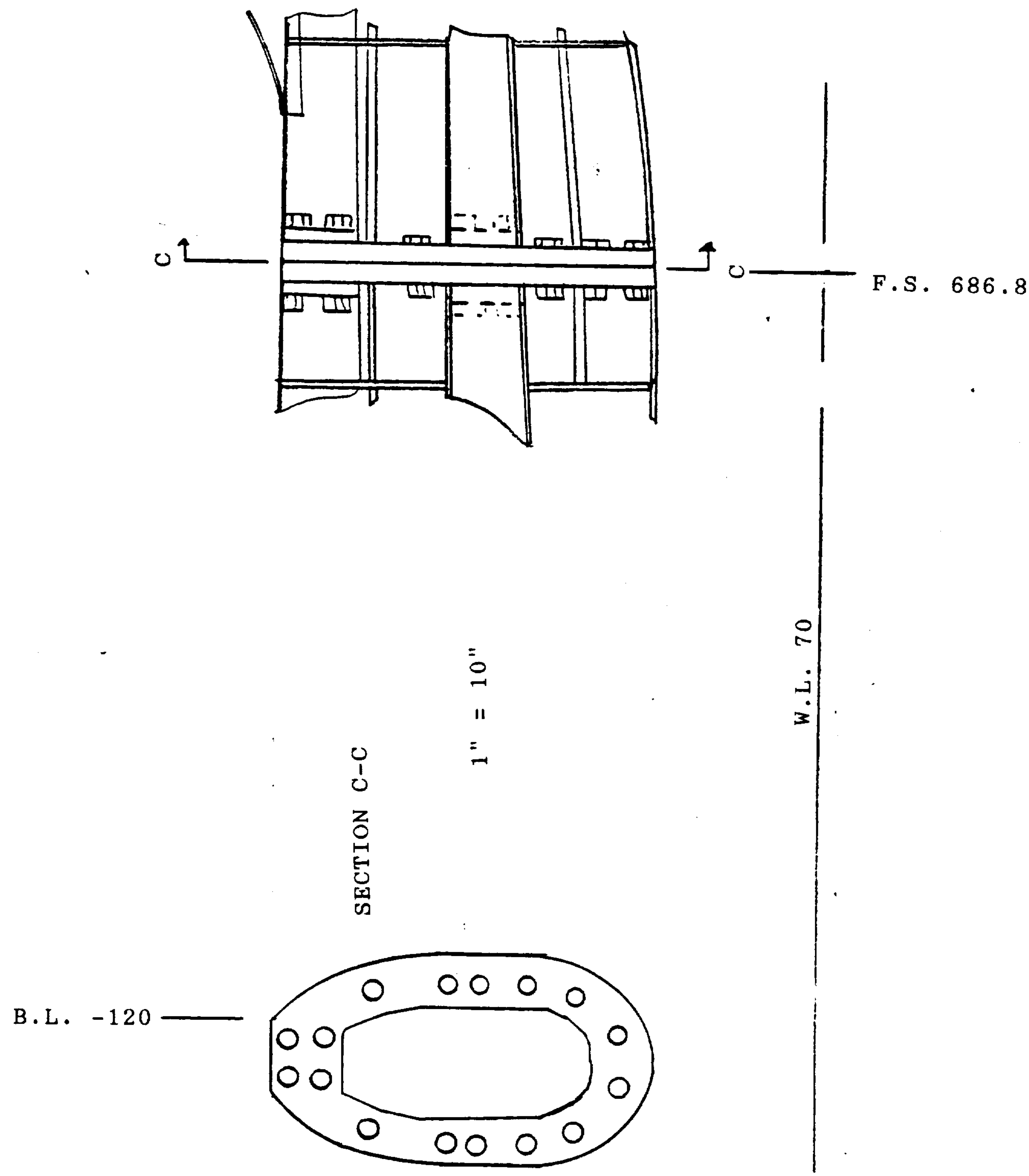

Figure 8.9d: Empennage attachment joint.

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The Ugly boom and main gear attachments suffer from the same problems as those of the Good aircraft. Figure 8.9d also shows the method used to attach the empennage section to the aft end of the boom. The empennage structure bolts directly onto the boom through mounting plates. The mounting bolts are in shear for vertical loads, but are in tension for longitudinal loads. Therefore, alternate designs should be examined.

<u>8.3.2 Horizontal Tail Extension Attachment</u>

Extensions to the horizontal tail are required on the Good and Bad aircraft, but not on the Ugly aircraft. Since the empennage is to be common between all three airplanes, these extensions need to be removable. The elevator hinge line is at the 70% chord point, but it is not known whether or not the elevator needs to extend into the extension. It is assumed for this section that the elevator will extend into the extension along a constant chord line. This simplifies the analysis of the performance of the stabilizer, but it complicates the operation of the extended sections because this creates a swept hinge line. With an unswept hinge, the elevator sections can be connected together. With a swept hinge line on the extension, the extended sections must be actuated by a mechanical linkage that connects them to the permanent elevator section. This adds weight and complexity, but simplifies lofting of the airfoil sections of the extension by placing the hinge line at a common chord point. Both of these options should be examined. Figures 8.10a-c present the detailed structural layout of the horizontal tail extension attachment, including a possible elevator interconnect link. This design allows the extended elevator sections to be actuated without any extra actuators. Structural provision has also been made for a mechanical rudder interconnect link. This link allows the actuators of either rudder to actuate both rudders in the event of a failure. If an actuator jams, this may prevent either rudder from operating, so this system should be designed so that the working actuator can either overpower the failed actuator, or disengage the link.

As designed, the extensions bolt onto the horizontal stabilizer at the spar caps. The mechanical elevator interconnect link is separated into two parts: One part is permanently attached to the main stabilizer, and the other part is permanently attached to the extension. A collar attached to the main stabilizer system connects the two parts when the extension is attached. When the extension is removed, the extended spar caps (a permanent part of the main stabilizer and vertical tail assembly) are covered with a bullet faring. When the elevator interconnect link is designed, care should be taken that the collar neither pierces the fairings nor falls through the cutout in the end rib at full elevator deflection. Since the linkage is not removed when the extension is removed, the linkage will continue to move as the elevator is deflected.

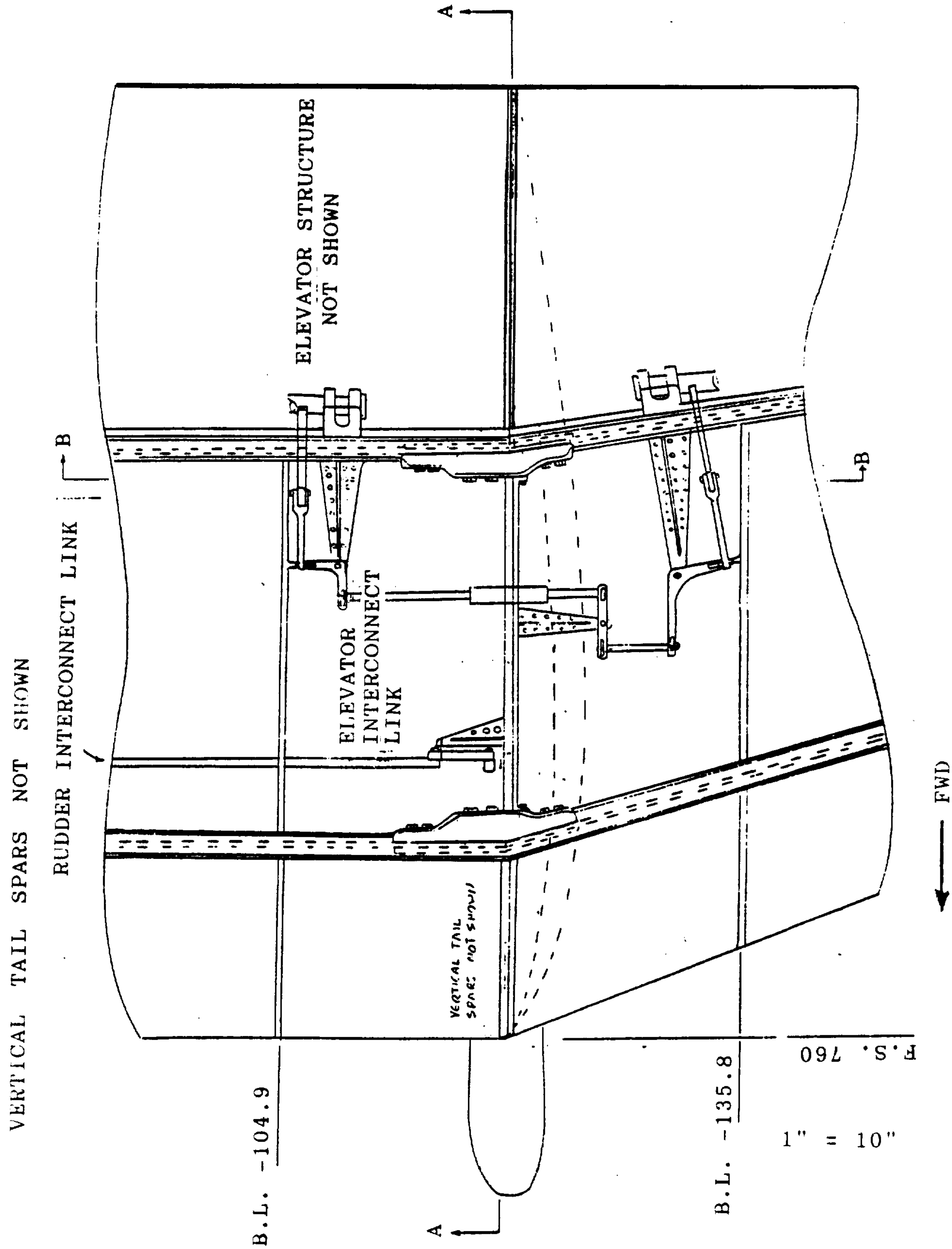

Figure 8.10a: Stabilizer extension joint top view.

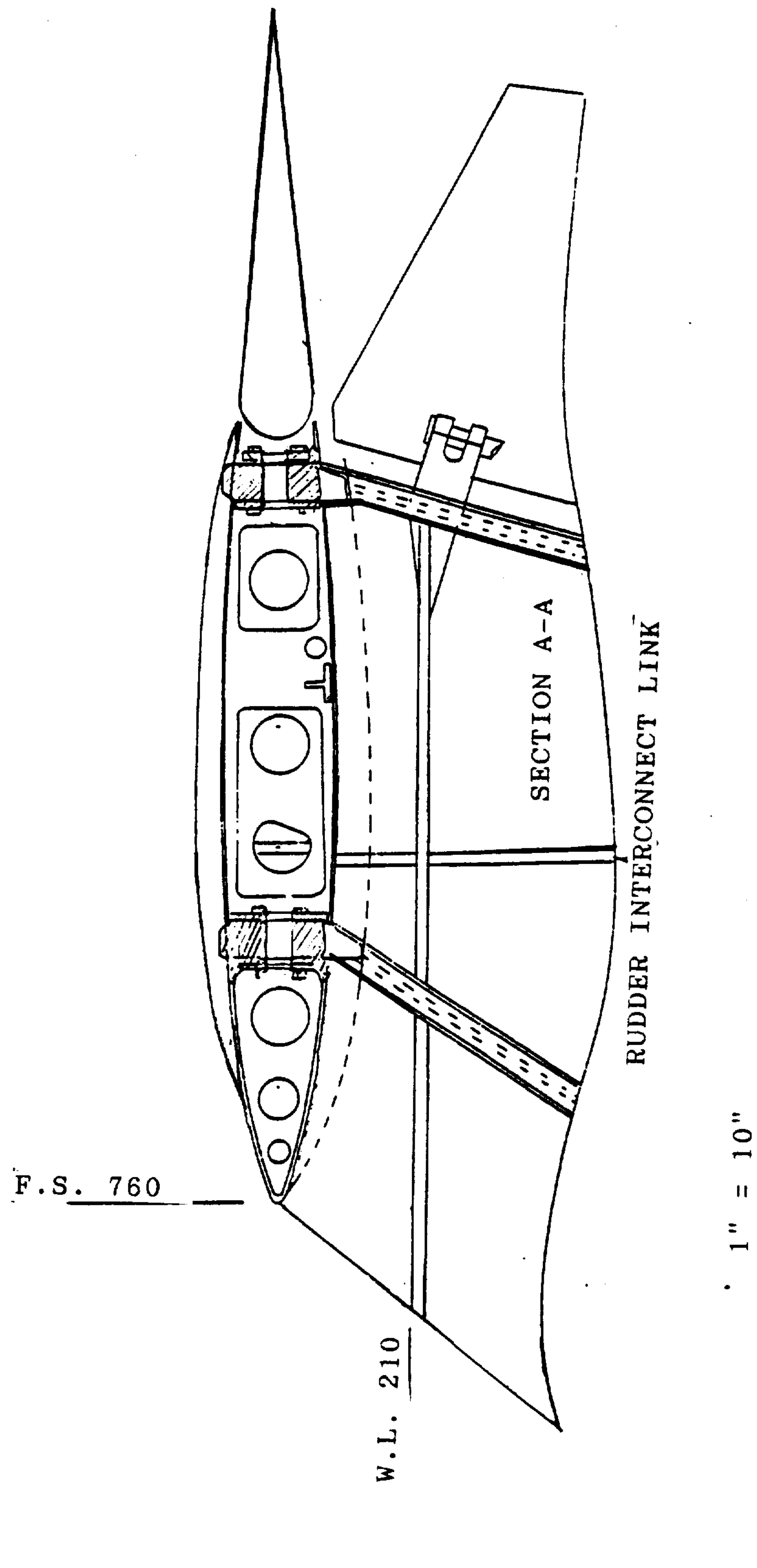

Figure 8.10b: Stabilizer extension joint side view.

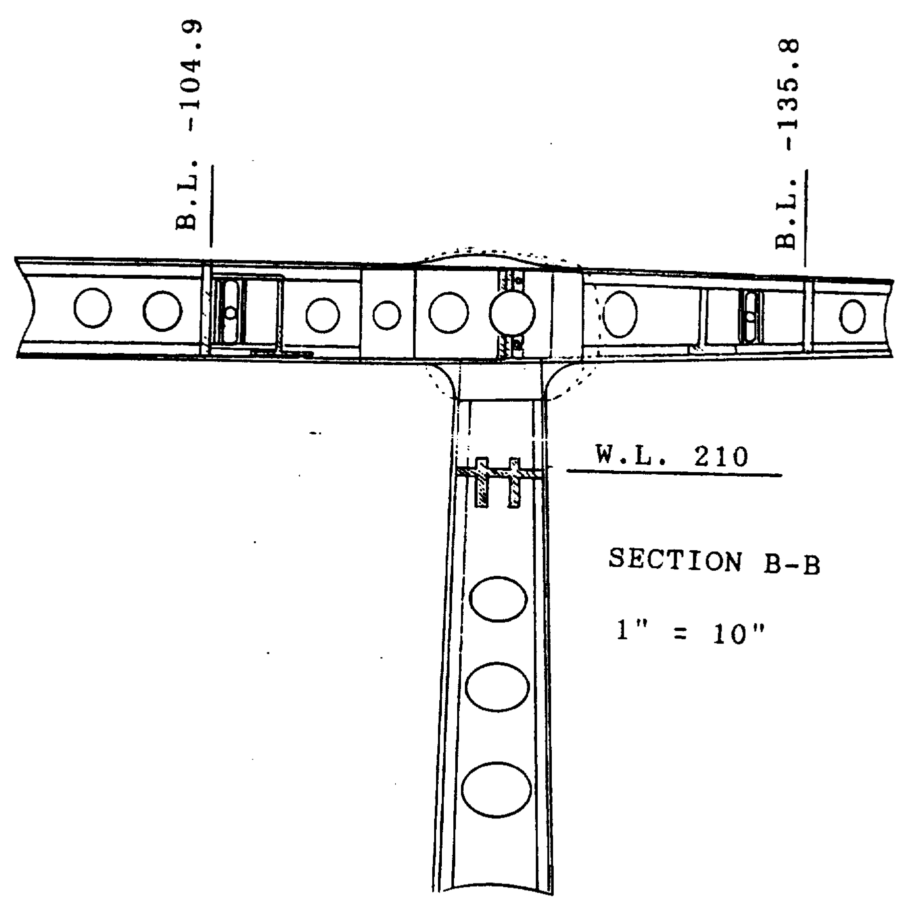

Figure 8.10c: Stabilizer extension joint front view.

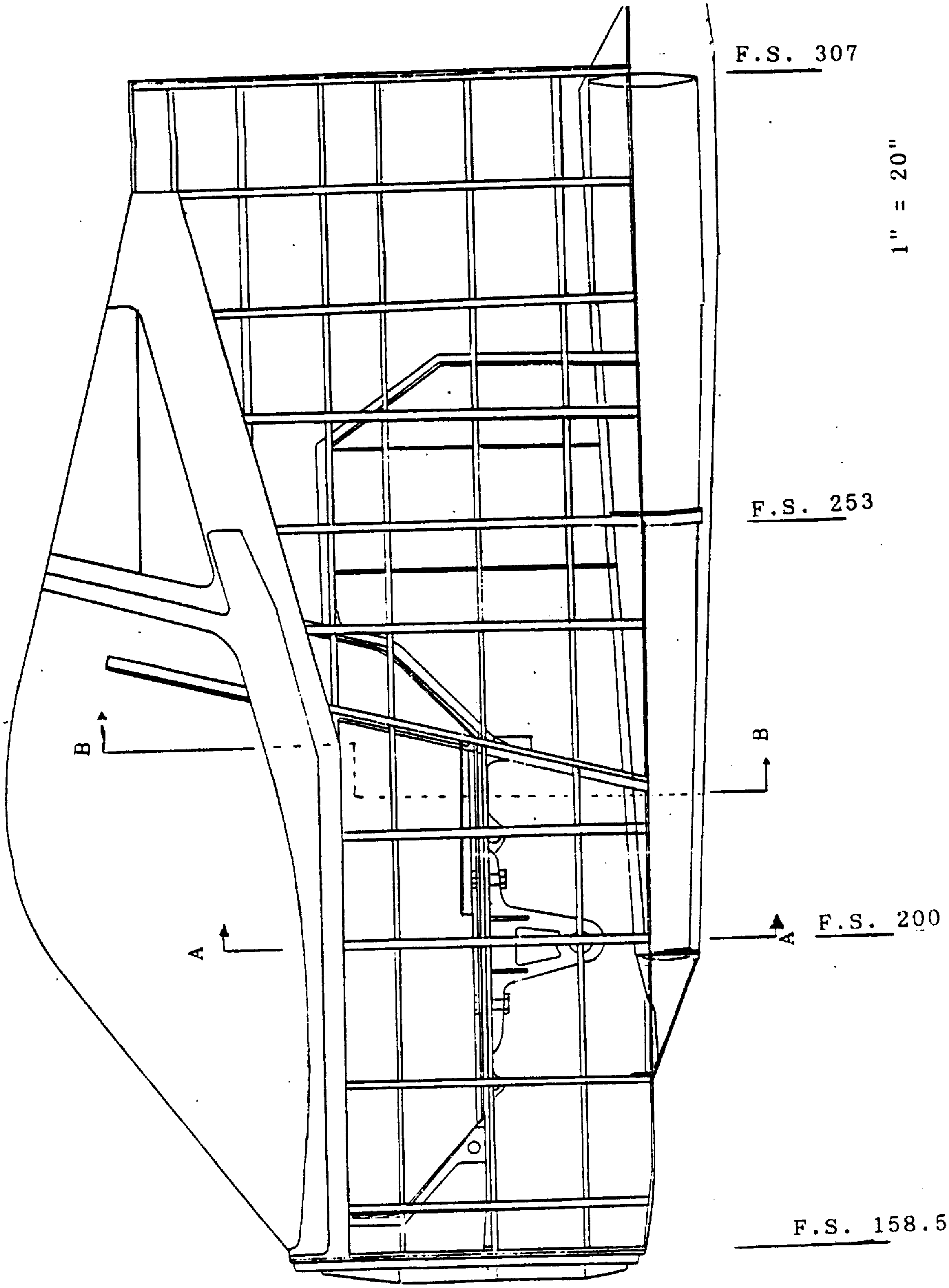

Figure 8.11a: Nose section side view.

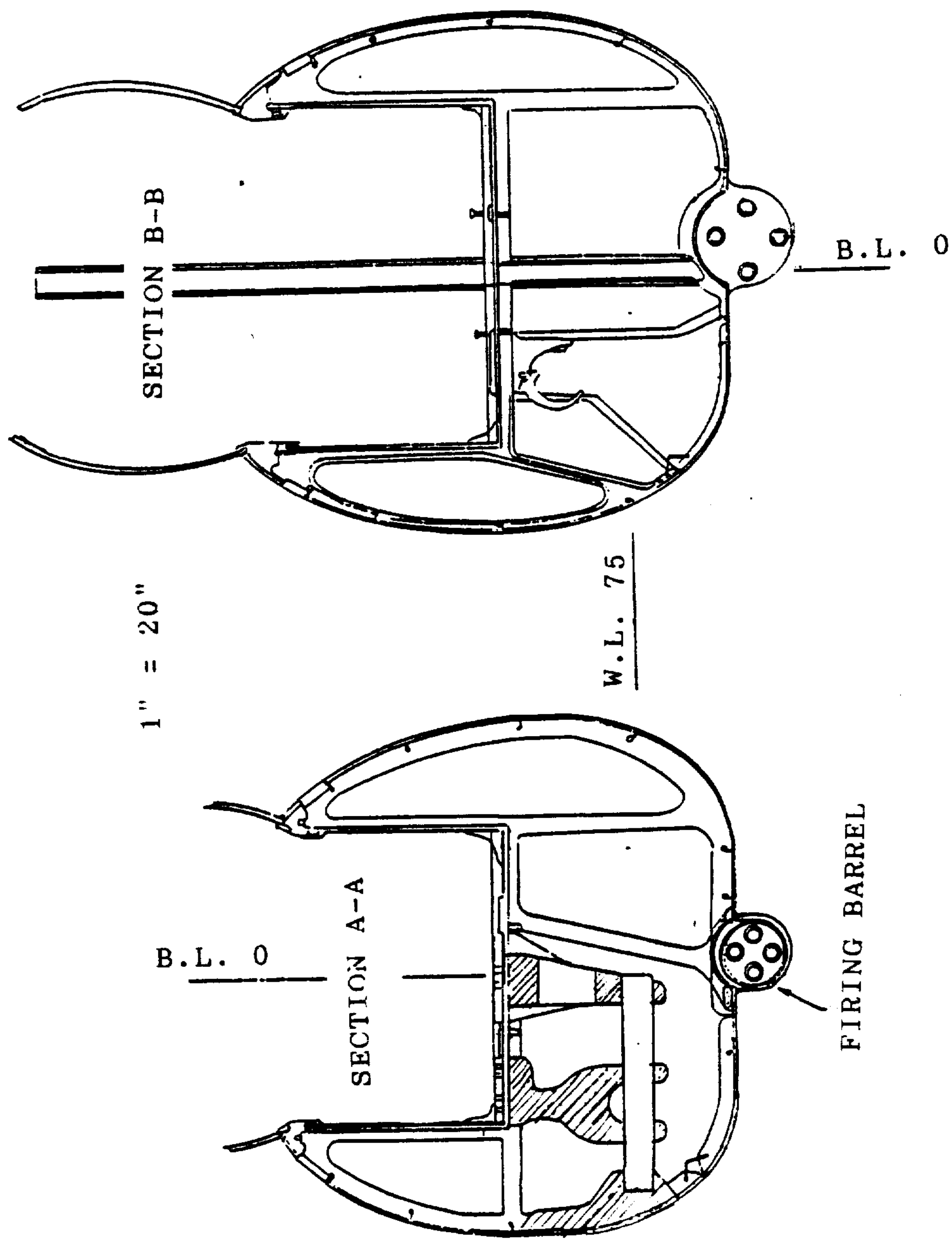

Figure 8.11b: Nose section cross sections.

8.3.3 Nose Section Detailed Structural Layout

The nose section is common to all aircraft and contains the cockpit, gun, radar, and nose gear. The landing gear is installed off center to allow the gun to be mounted on the center line of the airplane. To allow the nose wheel to retract without striking the gun, the gun is installed at an angle that places the firing barrel parallel to the wheel well and on the centerline of the airplane. The firing barrel is thus the closest barrel to the wheel well. The gun is placed so that center of the firing barrel is one inch below the lower surface of the fuselage. The nose gear mounts attach to the bottom of the cockpit and to stiffened fuselage frames. The ejection seat launch rail extends below the cockpit floor and helps support the gun, but this extension may not be necessary since the structure in this area is already very strong. This should be examined. Figures 8.11a-b show the nose section detailed structural layout.

8.4 Wing Component Sizing

The sizing of the wing skins, spars, and ribs has not been completed. The methods of Reference 20 were used to size the wing components for the Good airplane. Since the Good airplane has the highest wing loading of the three aircraft, the sizes determined by this method will be conservative for the other aircraft. An angle of attack of 12 degrees was chosen, and a speed of 558 fps was used. These values were chosen because they represent unstalled wing performance at ultimate load conditions. Since only one flight condition is being checked, a 15% safety factor has been included in all calculations. To accurately size the wing members all corners of the flight envelope should be investigated. For these calculations, the chosen flight condition is between the upper corners of the flight envelope. The following work was performed in the sizing of the wing components:

* The air loads were converted to normal, axial, bending moment, and torsional moment loads.
* Zero lift drag was approximated using the methods of Reference 16, and has been included in the loads calculations.
* The airfoil section was defined and a coordinate system established.
* The locations of all structural components were established.
* Wing section moments of inertia were calculated about the assumed wing elastic axis location. These moments of inertia are functions of the sizes of the structural members.

Sizing the members was accomplished be treating each load separately and adding the results. Sizing was at wing stations

360, 240, and 42 because these stations coincide with the wing section joints and the main wing root. These results were linearized to size all of the members of the wing. The completed work can be found in Appendix D.

The structure of the wing consists of ribs, spars, spar caps, skins, and stringers. Stringer areas were allowed to vary to minimize structural weight. Table 8.1 presents a summary of the stringer and spar cap locations for a typical airfoil section.

Table 8.1: Stringer and Spar Cap Locations for a Typical Airfoil Section (Coordinate system shown below)
Note: The origin is at the elastic axis.

Component	X coordinate (chord fraction)	Z coordinate (chord fraction)
A	.250	.067
B	.250	-.051
C	-.245	.045
D	-.245	-.025
a	.150	.082
b	.050	.084
c	-.050	.078
d	-.150	.065
e	.150	-.062
f	.050	-.063
g	-.050	-.056
h	-.150	-.044

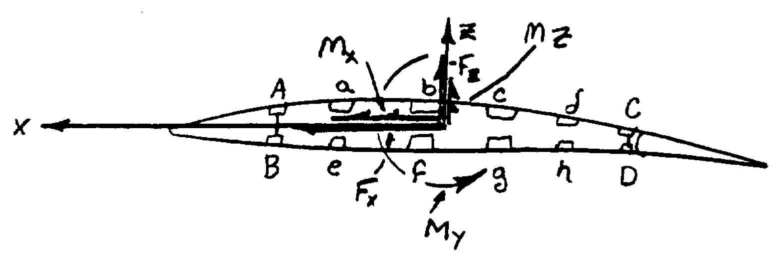

Table 8.2 presents the loads on the wing for 12 degrees angle of attack, 558 fps, Sea Level standard conditions.

Table 8.2: Air loads on the Wing, a= 12 deg, V = 558 ft/s, Sea Level

Load	Value at: B.L. 360	B.L. 240	B.L. 42
Mx (ft.lb)	160,000	660,000	2,500,329
Mz (ft.lb)	-22,500	-99,000	-380,000
My (ft.lb)	210,000	370,000	390,000
Fz (lb)	32,000	74,000	150,000
Fx (lb)	36,000	86,000	174,000

The structural members of the wing were sized with the methods of Reference 20, with an additional safety factor of 15% to account for other critical flight conditions that were not checked. The work performed to size the structural members may be found in Appendix D. Tables 8.3 - 8.5 show the results of the wing component sizing.

Table 8.3: Spar Cap and Stringer Sizing Results

Item	Cross-Sectional Area (sq. in.)			
	Root	B.L.240	B.L.360	B.L.501
A	4.04	1.56	0.46	0.16
B	2.49	0.96	0.29	0.10
C	2.27	0.88	0.25	0.09
D	1.61	0.62	0.19	0.06
a	4.77	1.84	0.53	0.18
b	4.76	1.84	0.53	0.18
c	4.37	1.69	0.49	0.17
d	3.51	1.35	0.40	0.14
e	3.20	1.23	0.23	0.12
f	3.35	1.31	0.37	0.13
g	3.05	1.17	0.35	0.12
h	2.52	.97	0.28	0.10

Material used: 2024 Aluminum + 20% SiO_2 extrusion.

Table 8.4: Wing Skin, Spar, and Rib Thicknesses.

Item	Thickness (inches)		
	ROOT	B.L.240	B.L.360
Front Spar	0.940	0.680	0.370
Rear Spar	0.940	0.680	0.370
Top Skin	0.040	0.040	0.030
Bottom Skin	0.040	0.040	0.030
Ribs	0.040	0.040	0.030

Spars and ribs use 2024 Aluminum + 20% SiO_2 extrusions and stampings, while skins use ARALL. These materials have similar properties, but ARALL is stiffer.

Table 8.5: Wing Moments of Inertia.

	Section Moment of Inertia (in^4)			
	ROOT	B.L.240	B.L.360	B.L.501
Ix	6,300	1,200	230	25
Iy	1,100	200	39	4
Iz	69,000	9,200	2,200	200
Ixz	45,000	8,800	1,900	190

8.5 Flutter Analysis of the Wing

Because of the large wing span of the Good aircraft, a flutter analysis was performed. The purpose of the analysis was to determine the flutter speed of the wing. When the wing is moving forward at some constant velocity and it is suddenly disturbed, the subsequent motion may be such that the amplitudes of vibration tend to decrease, stay constant, or increase. The speed at which the amplitudes of vibration tend to remain constant is called the critical flutter speed (Reference 21). At speeds higher than this critical speed, the amplitudes will diverge and may cause the wing to destruct. The critical flutter speed must be at least 1.4 times the maximum dive speed.

The methods and calculations for this analysis are shown in Appendix D. The results of the analysis are that the critical flutter speed is greater than 4935 knots and less than 1817 knots. This result is nonsense, meaning one or more mistakes were made in the analysis. The possible mistakes are:

1) The structural damping term was omitted. This term is usually small compared to the others and its effect would be small.
2) The system was assumed to be quasi-steady state. That is, the aerodynamic forces were assumed to occur instantaneous with wing deflection. The Kussner-Wagner functions should have been checked.
3) The bending and torsional deflection mode shapes were for a uniform, constant cross-section beam. The wing is tapered, thus this assumption is bad.
4) Others, that through inexperience, are there but not known.

9. SYSTEMS

The purpose of this chapter is to present the systems layout for the Good, the Bad, and the Ugly aircraft. Because of the high degree of commonality between the three aircraft's systems, ghost views showing the systems are only shown for the Good aircraft. The system components were chosen by first reviewing the mission specifications to determine what the aircraft were to do and second, by observing the systems of aircraft with similar missions.

The flight control system is shown in Section 9.1. The hydraulic and electrical systems are shown in Sections 9.2 and 9.3, respectively. Section 9.4 shows the fuel system. The environmental control and anti-ice system are shown in Section 9.5 and the internal armament and avionics are shown in Section 9.6.

9.1 Flight Control System

The lateral, directional, and longitudinal flight control system layouts are shown in Figures 9.1 through 9.3, respectively. The flight control system has double redundant signal paths to hydraulic actuators for the longitudinal, lateral, and directional flight control surfaces. The hydraulic actuators are single redundant. The redundancy in the actuators is obtained by separating the control surfaces. The elevator, rudders, and ailerons are split into two separate surfaces, each having its own hydraulic actuator. This single redundant actuator is then powered by two independent hydraulic systems (see Section 9.2). The idea is that if one surface becomes inactive - i.e. combat damage to the surface, actuator, signal path, or hydraulic line - the other surface would be able to provide adequate control power. Adequate, however, does not mean Level 1 handling quality. It may be the case that losing two of the four rudder surfaces drops the handing qualities to Level 2 or 3. This, however, could be acceptable for a military aircraft that only needs to get back to its base. Another added benefit of this flight control system is that the hydraulic actuator could all be the same size. To do this, the control surfaces must be split such that the aerodynamic loads on each surface are within the same range. This level of detail design was not done for these aircraft. The control surfaces then were split into two sections to illustrate the concept.

The sizing of the actuators could not be done due to the lack of detail design in the following two areas: 1) actuator to surface installation and 2) hinge moment derivative calculations. If more detail design had been done in these two areas, then the actuator piston area, the control surface deflection rate, and the hydraulic fluid flow rate could have been calculated.

Reference 22 outlines six major design problems involved with an irreversible system (of which a fly-by-wire system

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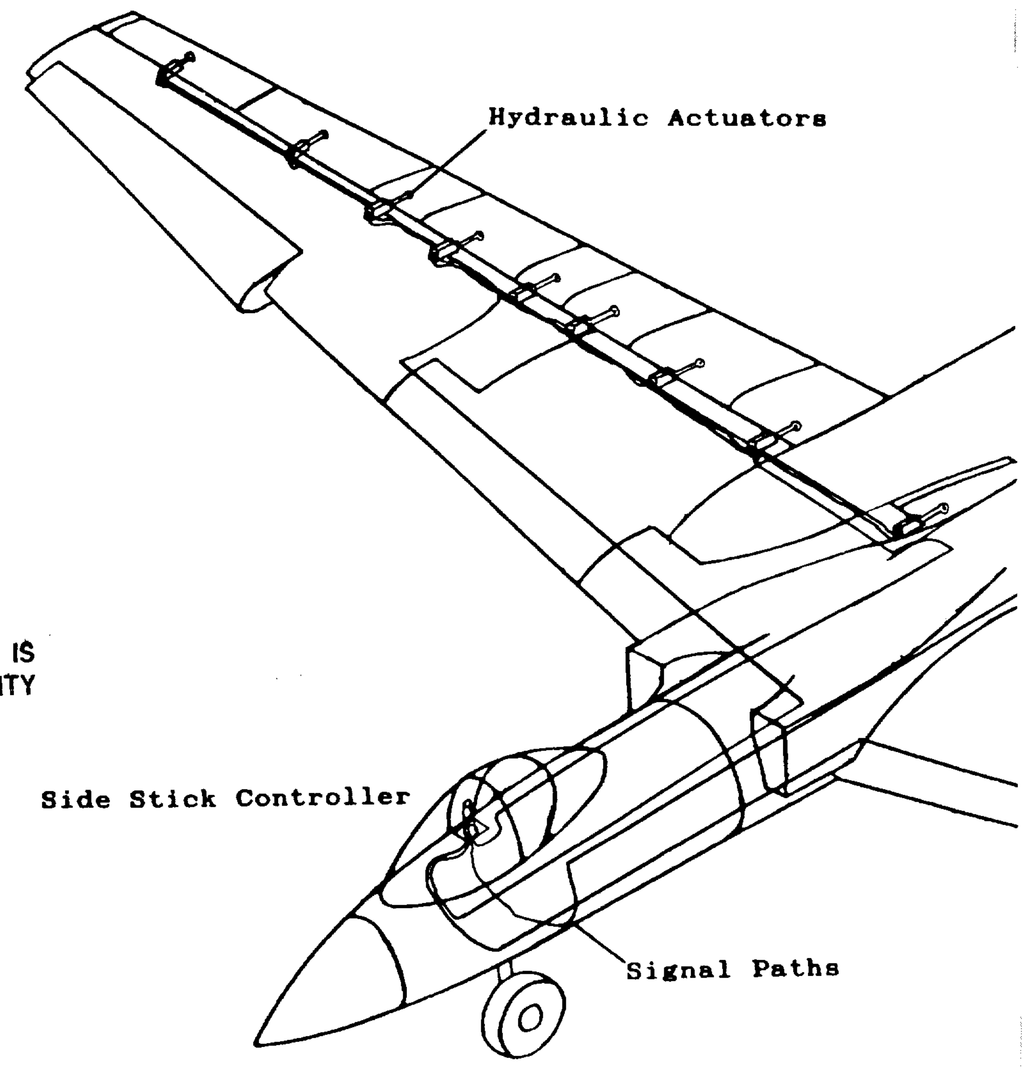
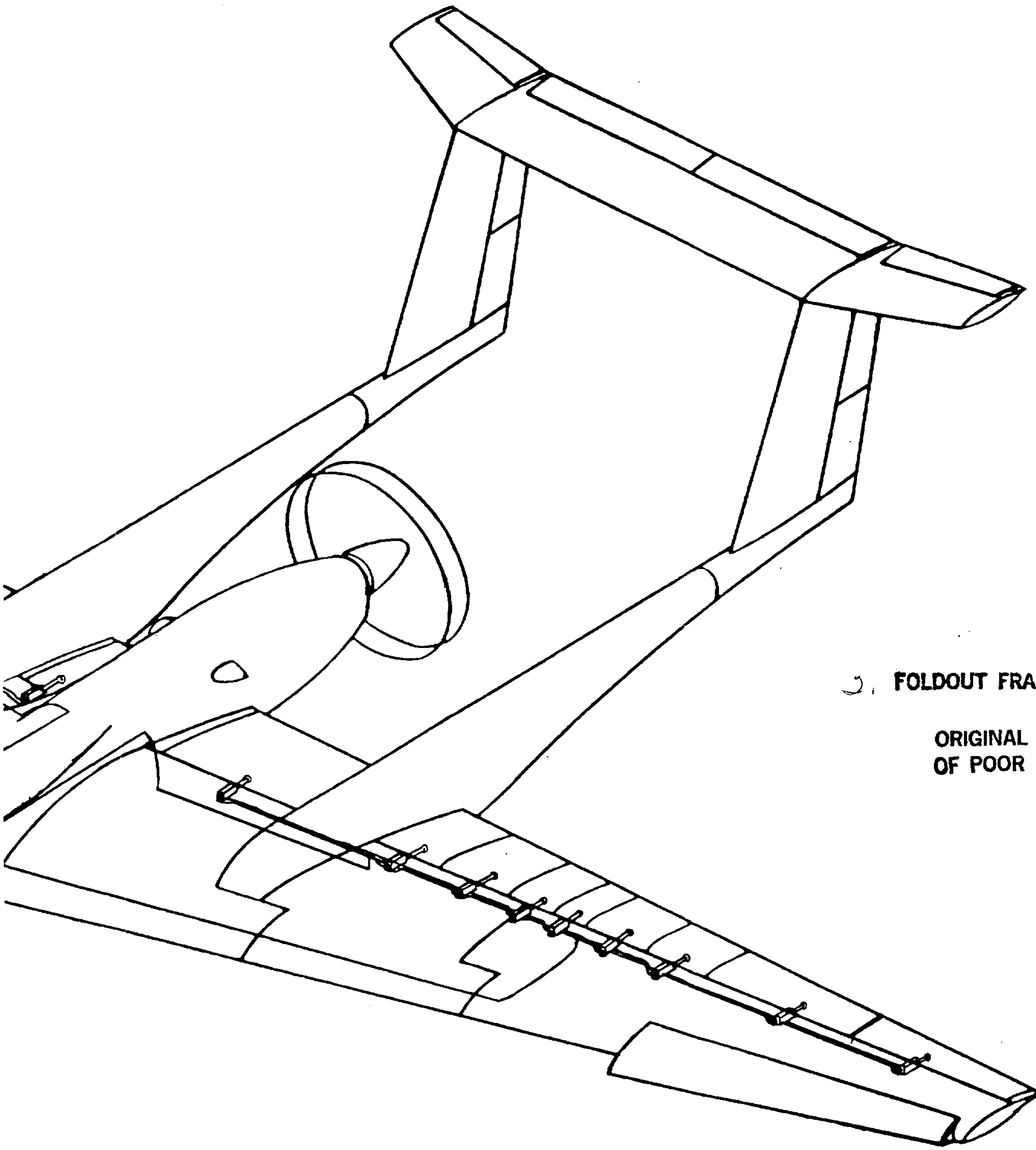


Figure 9.1 The Good: Lateral F



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Lateral Flight Control System Layout

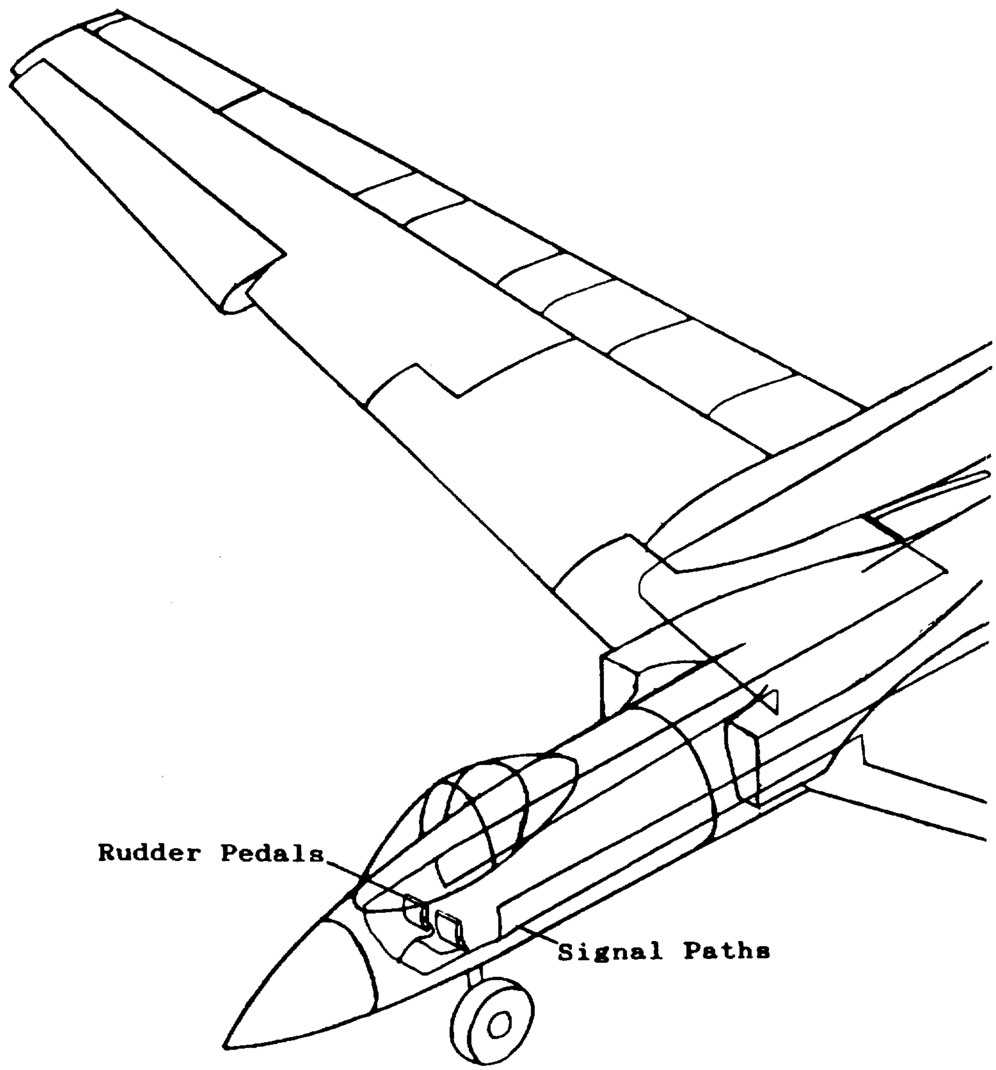
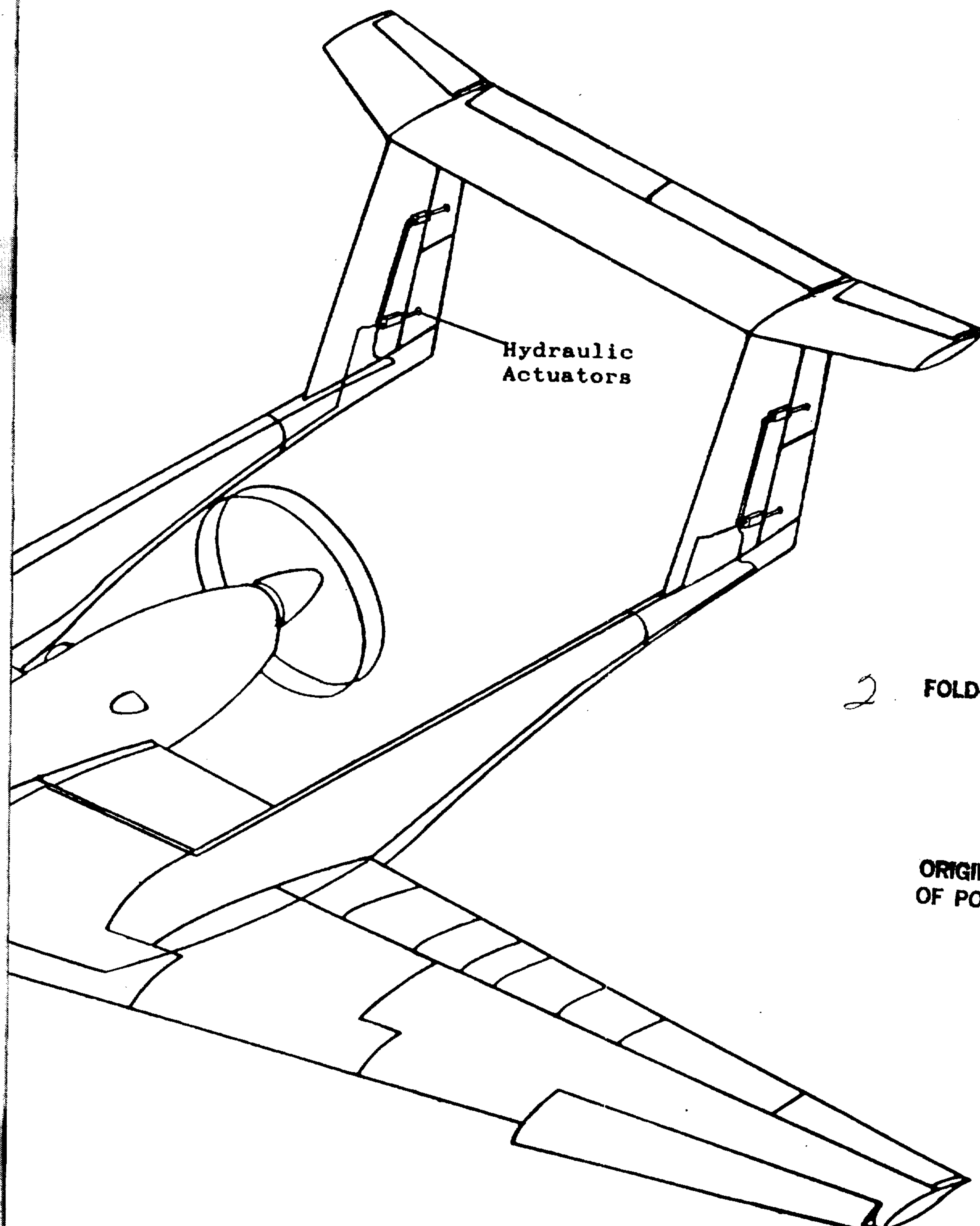


Figure 9.2 The Good: Directional



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Flight Control System Layout

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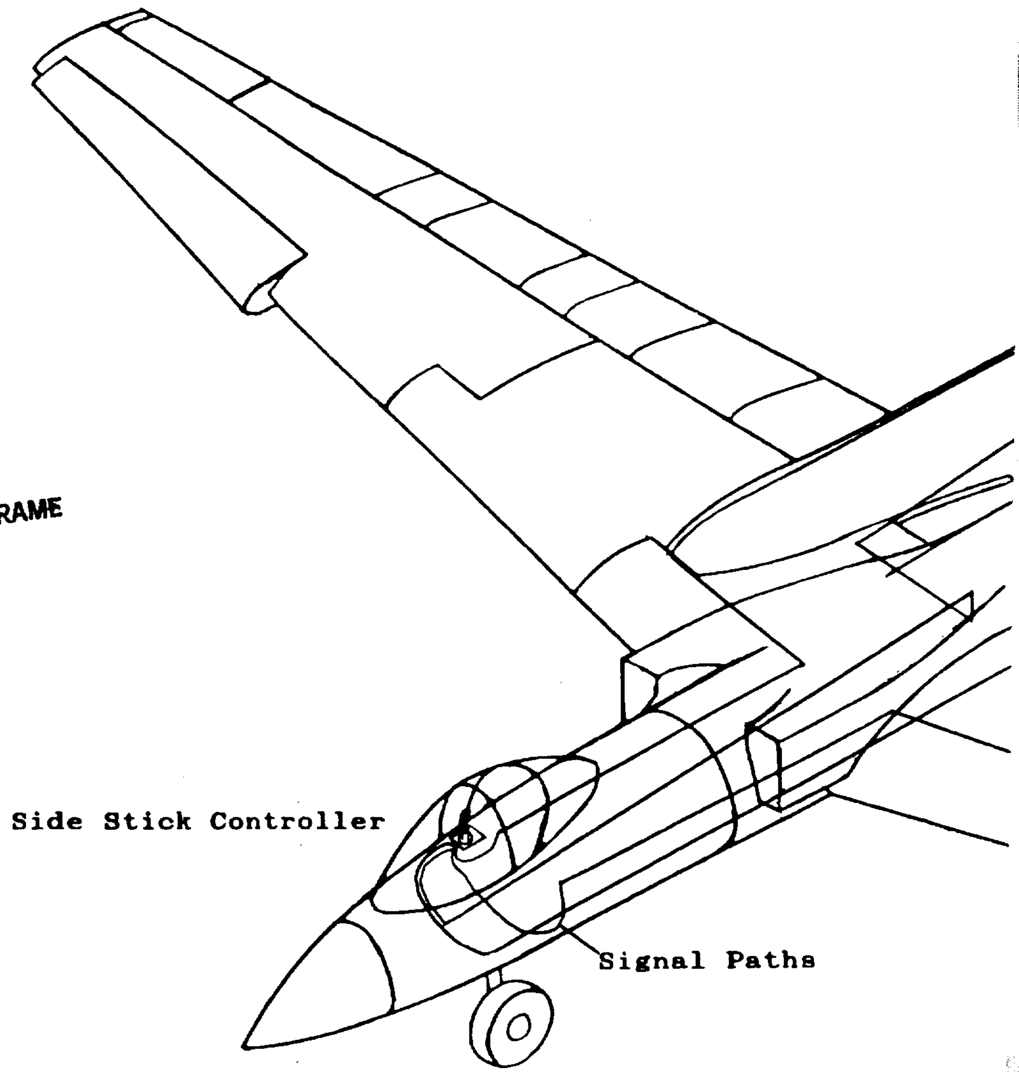
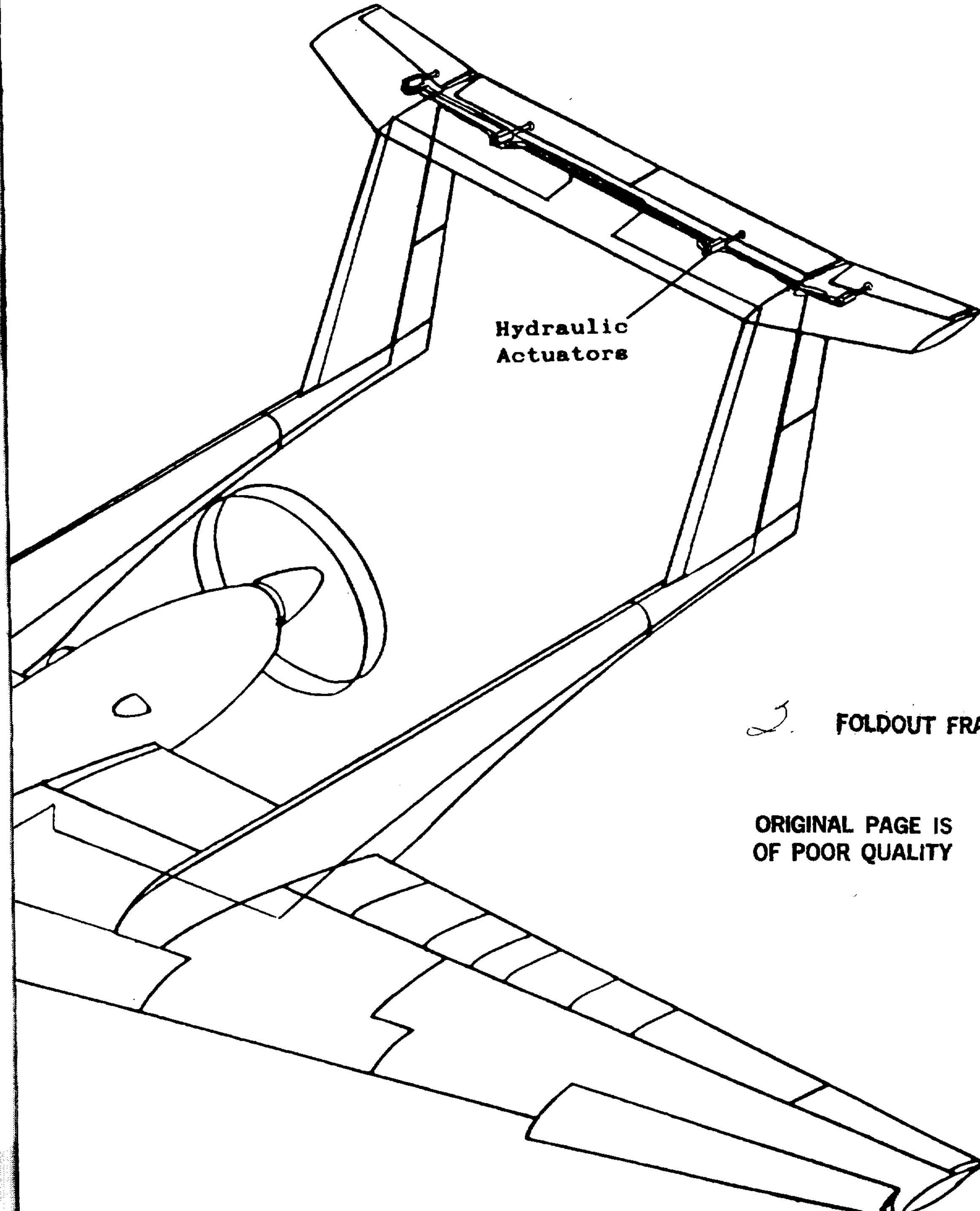


Figure 9.3 The Good: Longitud



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inal Flight Control System Layout

belongs). They are:

1) Complexity
2) Reliability
3) Redundancy
4) Cost
5) Accessibility for repairs
6) Susceptibility to lightning strike

Reference 22 also points out three major advantages of an irreversible flight control system:

1) Flexibility in combining pilot control commands with automatic control commands
2) Ability to tailor handling qualities
3) Potential weight savings

Another advantage of the fly-by-wire systems for these three aircraft is derived from commonality considerations. Commonality is increased by laying wires in the airframe as opposed to detail designing three separate mechanical systems for the three aircraft.

The flight control system layouts of the Bad and Ugly aircraft are identical to the Good's, the only difference is the amount of actuators required for the lateral control system.

9.2 Hydraulic System

The hydraulic system for the Good is shown in Figure 9.4. The hydraulic system consists of two independent systems (System A and B) operating at 3,000 psi pressure with a flow rate between 20-50 U.S. gallons/minute. The system pressure value was estimated by observing what is used for similar aircraft (aircraft data from Reference 8). The hydraulic fluid flow rate also had to be estimated this way because of the reasons already discussed in Section 9.1.

Hydraulic power is used for the following:

* power for the flight control system actuators
* main and nose gear steering, breaking, and retraction
* power for the internal gun

Two independent hydraulic systems are used to have redundancy in the flight control system. System A and B both supply power to every control surface actuator. The hydraulic lines were separated as much as possible to avoid loss of both systems due to combat damage in one area of the aircraft.

The Good and Bad use two engine driven hydraulic pumps. The Ugly, because it only has one engine, uses on engine driven pump and one electric driven pump. The only other difference between the aircraft is the hydraulic fluid flow rate. The flow rates are less for the Bad and the Ugly.

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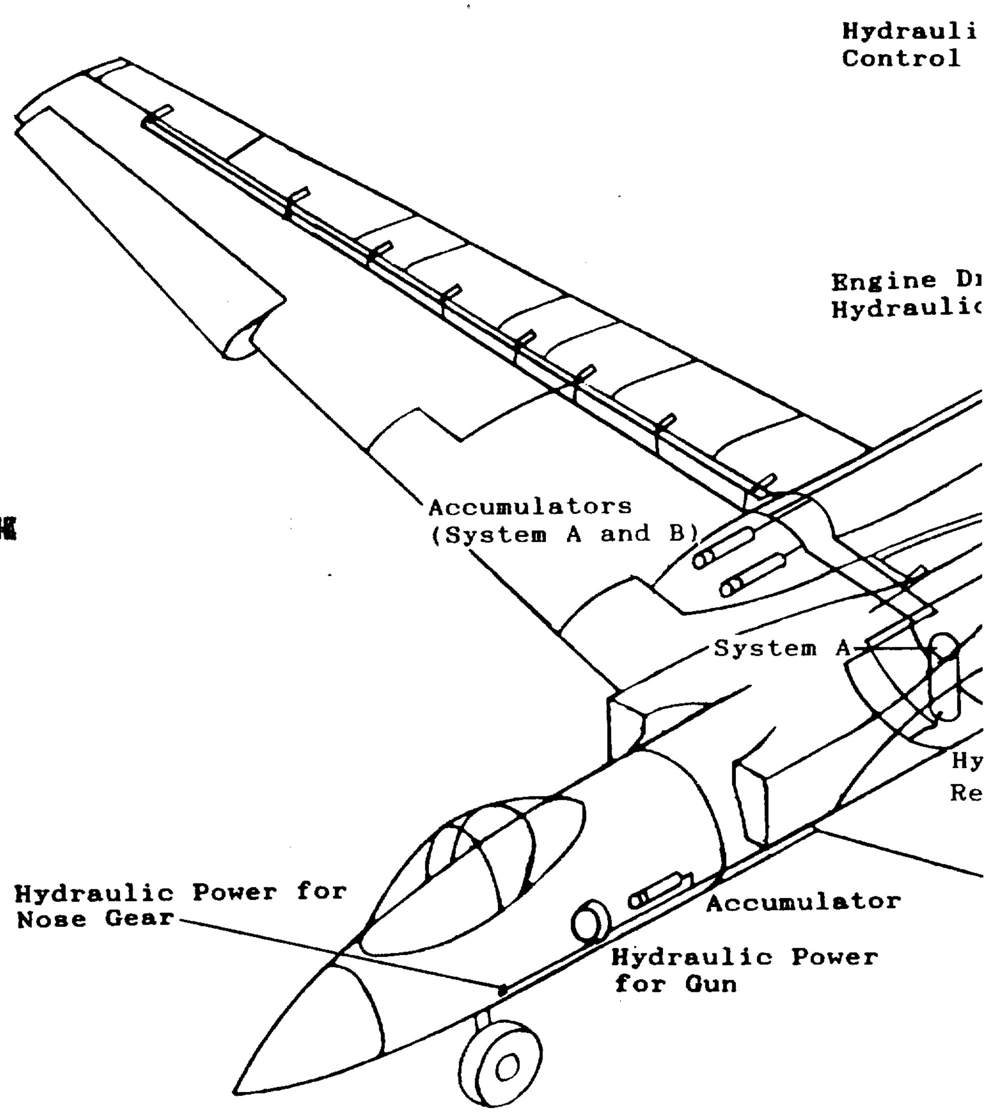
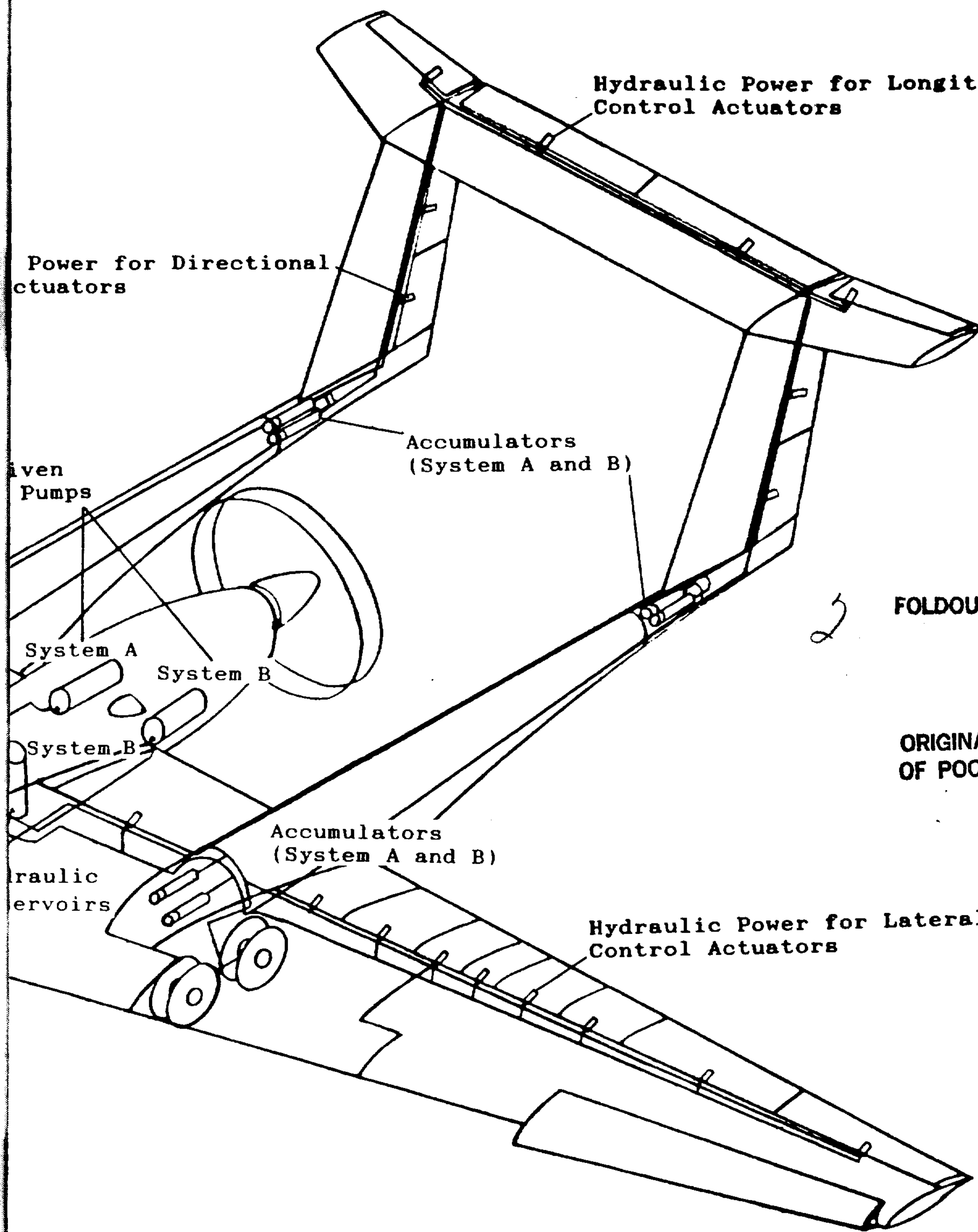


Figure 9.4 The Good: Hydra



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lic System Layout

9.3 Electrical Systems

The electrical system for the Good is shown in Figure 9.5. The electrical system consists of two engine driven generators to derive AC power. The generator power varies between 30-50 KVA depending on the aircraft (the Ugly needing the least and the Good the most power). A detailed power analysis was not done because of lack of information available on the power requirements of the aircraft's electrical system components. However, with more time and research (research such as talking to industry personnel), the analysis could have been done. A transformer/rectifier is used to get DC power for the aircraft systems requiring electrical power. Electrical power is required for the following:

* Internal and external lights
* Avionic and cockpit instrumentation
* Internal gun firing

Backup electrical power is supplied by a ram air turbine (RAT) which, stored in the port boom, drops in the freestream air in the case of main electrical generator failure.

9.4 Fuel System

The fuel system for the Good is shown in Figure 9.6. The fuel is stored in self-sealing, tear resistant, foam protected tanks. As much fuel as possible was placed in the fuselage for combat damage considerations. The fuel system consists of fuel pumps, fuel sumps, and a fuel vent system. The system also allows for single point re-fuelling on the underside of the port wing. The fuel system layout is identical for the Bad and Ugly airplanes except for the amount of fuel required.

The placement of the fuel jettison is pending upon further research. The probe is behind the engine inlets but is forward of the exhaust. The exhaust is on the top of the fuselage while the jettison probe is on the bottom. A problem may still exist, however, with the fuel vapor being carried by the pressure field about the fuselage into the exhaust stream. To properly locate the probe, a three dimensional flow analysis followed by a wind tunnel smoke test should be done.

9.5 Environmental and Anti-Ice System

The environmental control and anti-ice system for the Good airplane is shown in Figure 9.7. The environmental control system consists of air conditioning for the crew station and the avionics bays. The air conditioning is run from freestream air which is routed through a heat exchanger. The anti-ice system is an air heated spray tube system. Hot bleed air from the engines is piped through spray tubes in the leading edges of the wing, empennage, and engine inlets during known or suspected icing conditions.

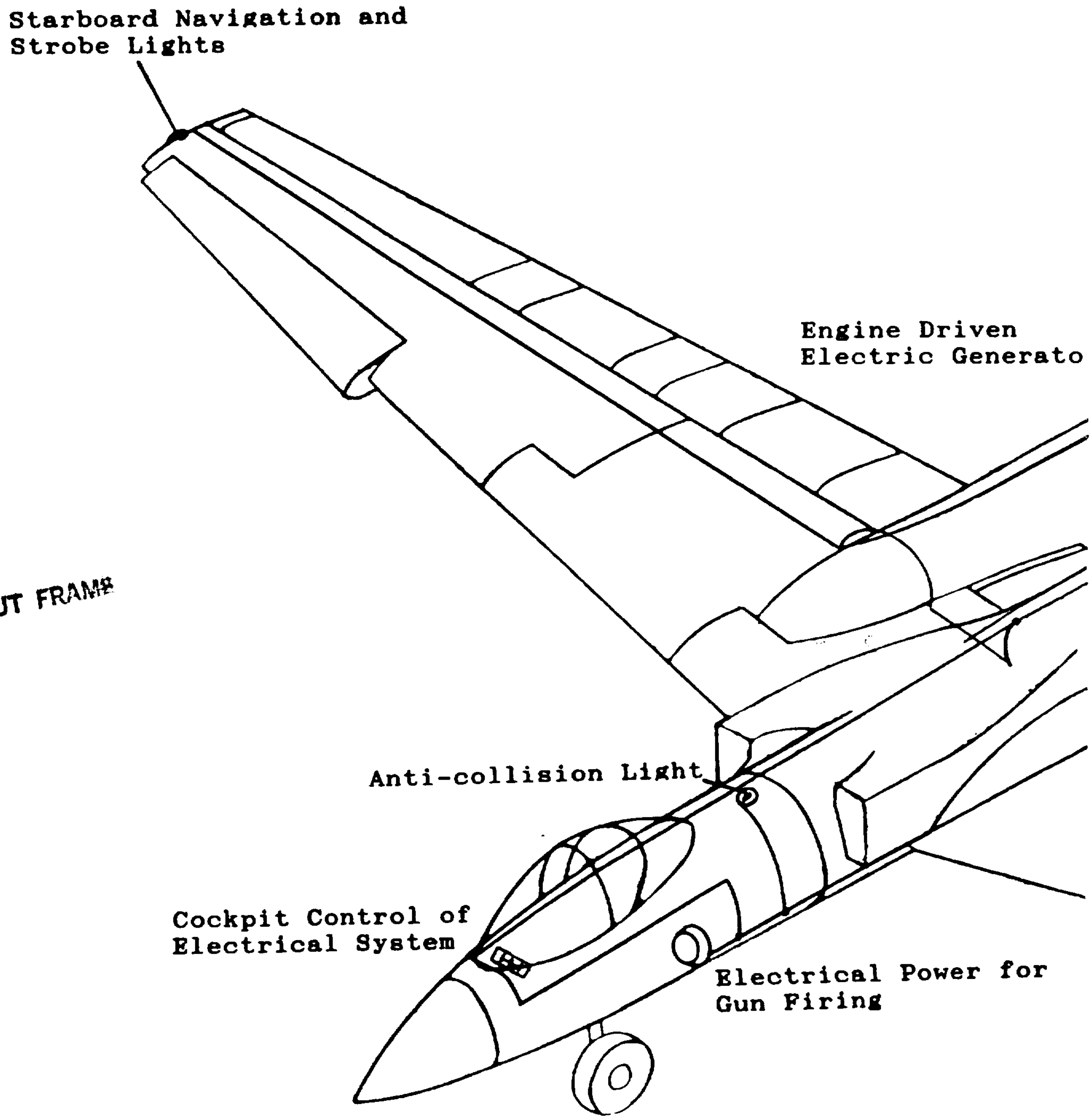
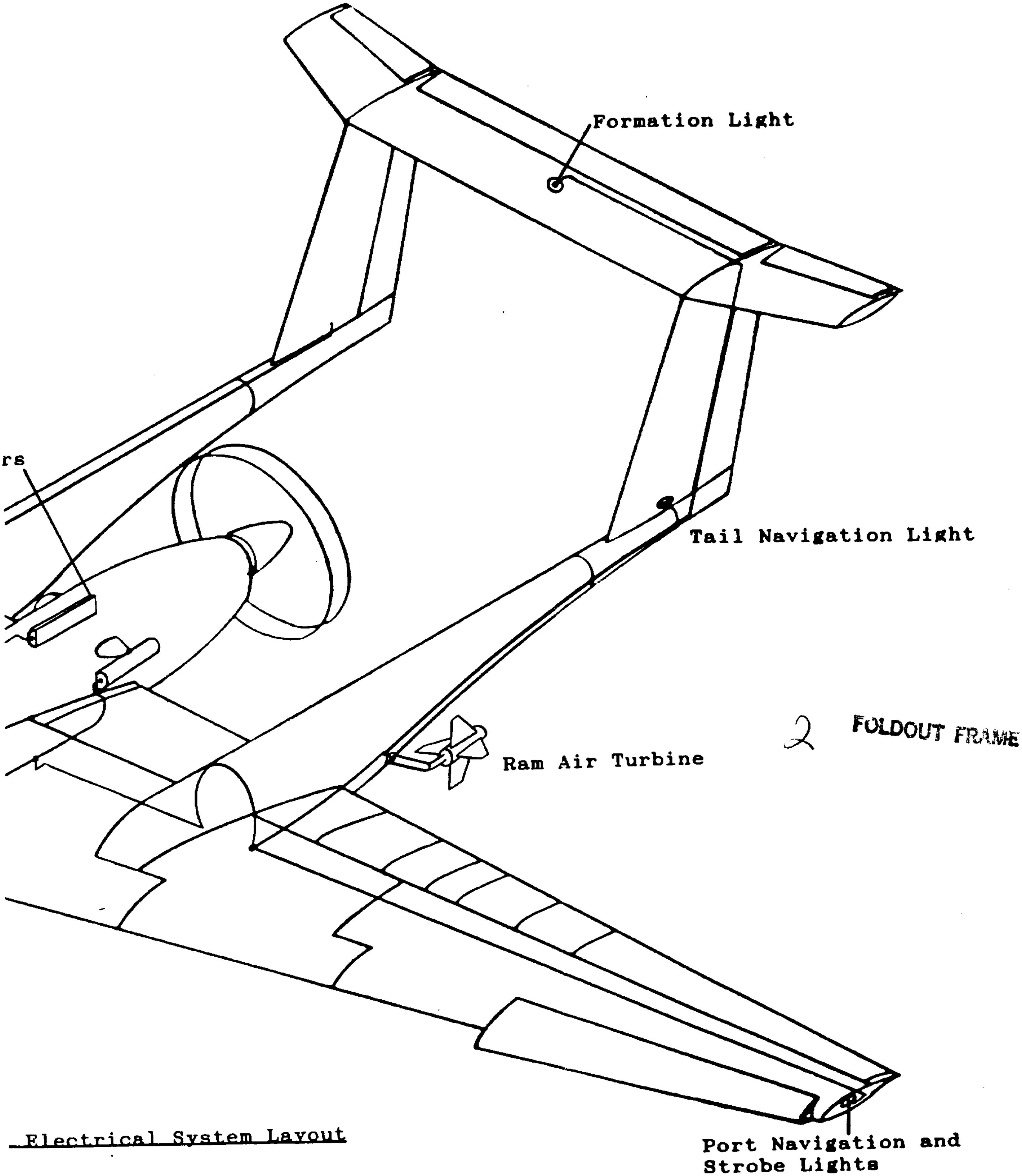


Figure 9.5 The Good:



Electrical System Layout

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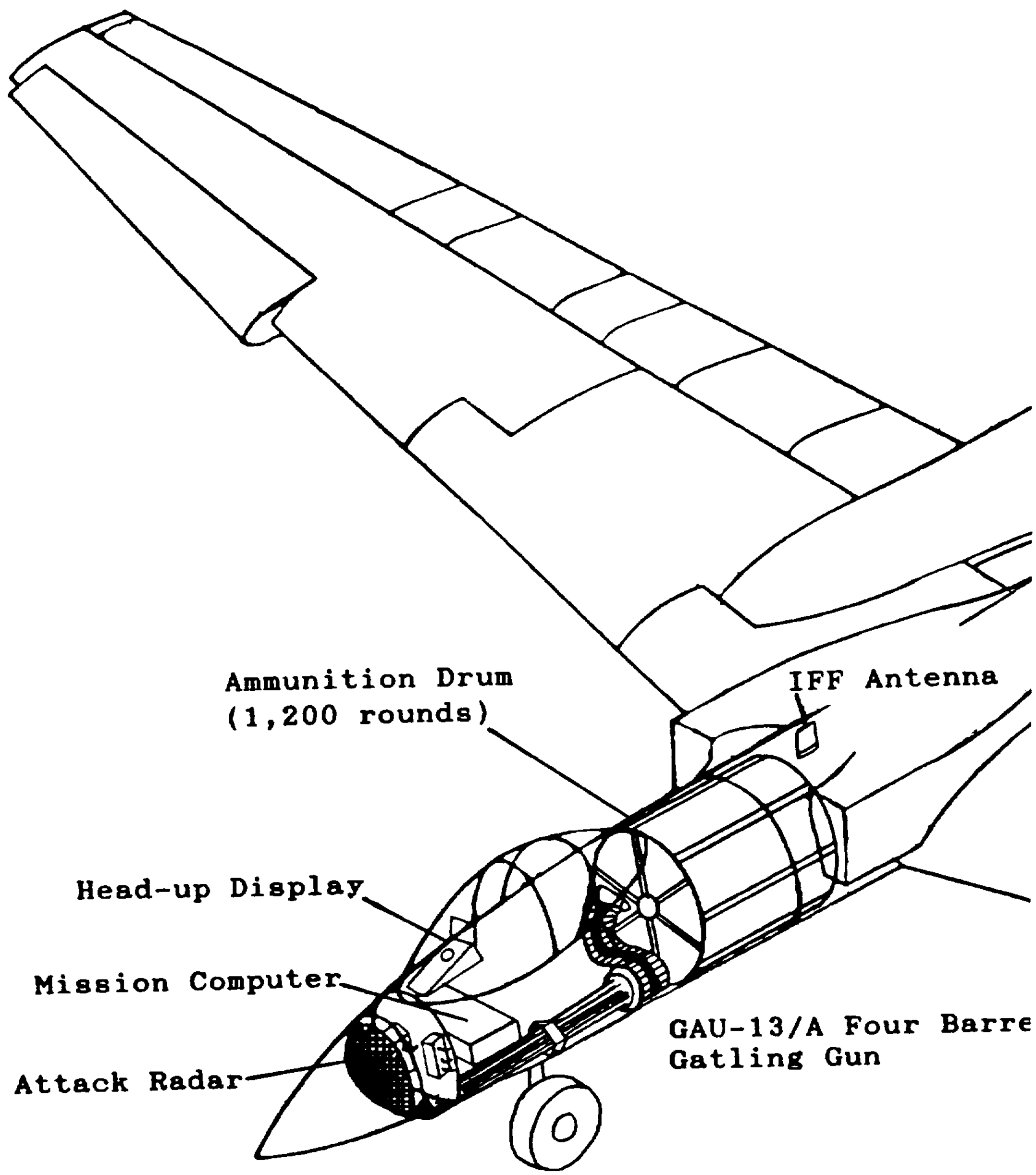
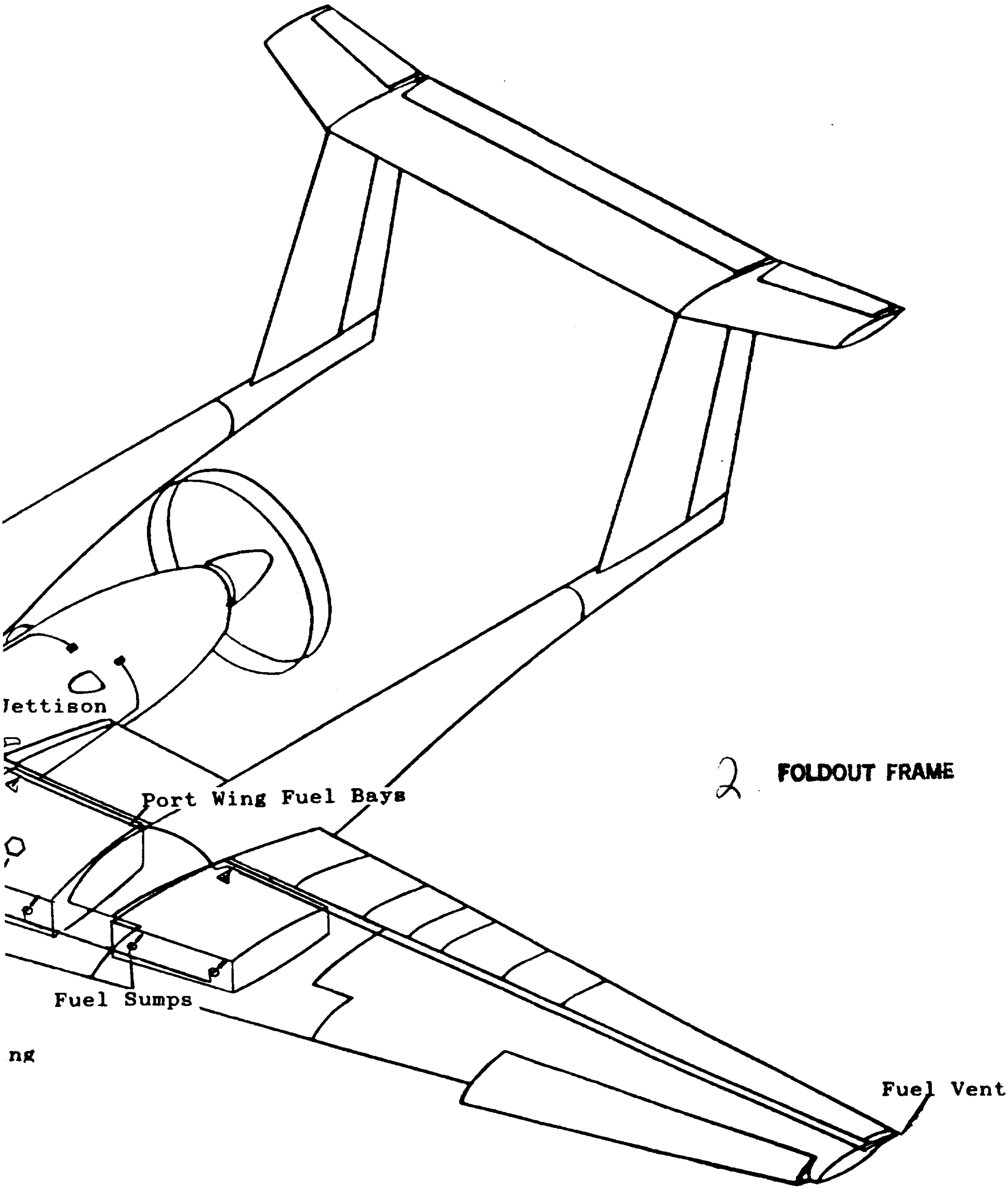


Figure 9.8 The Good: Inter



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Fuel System Layout

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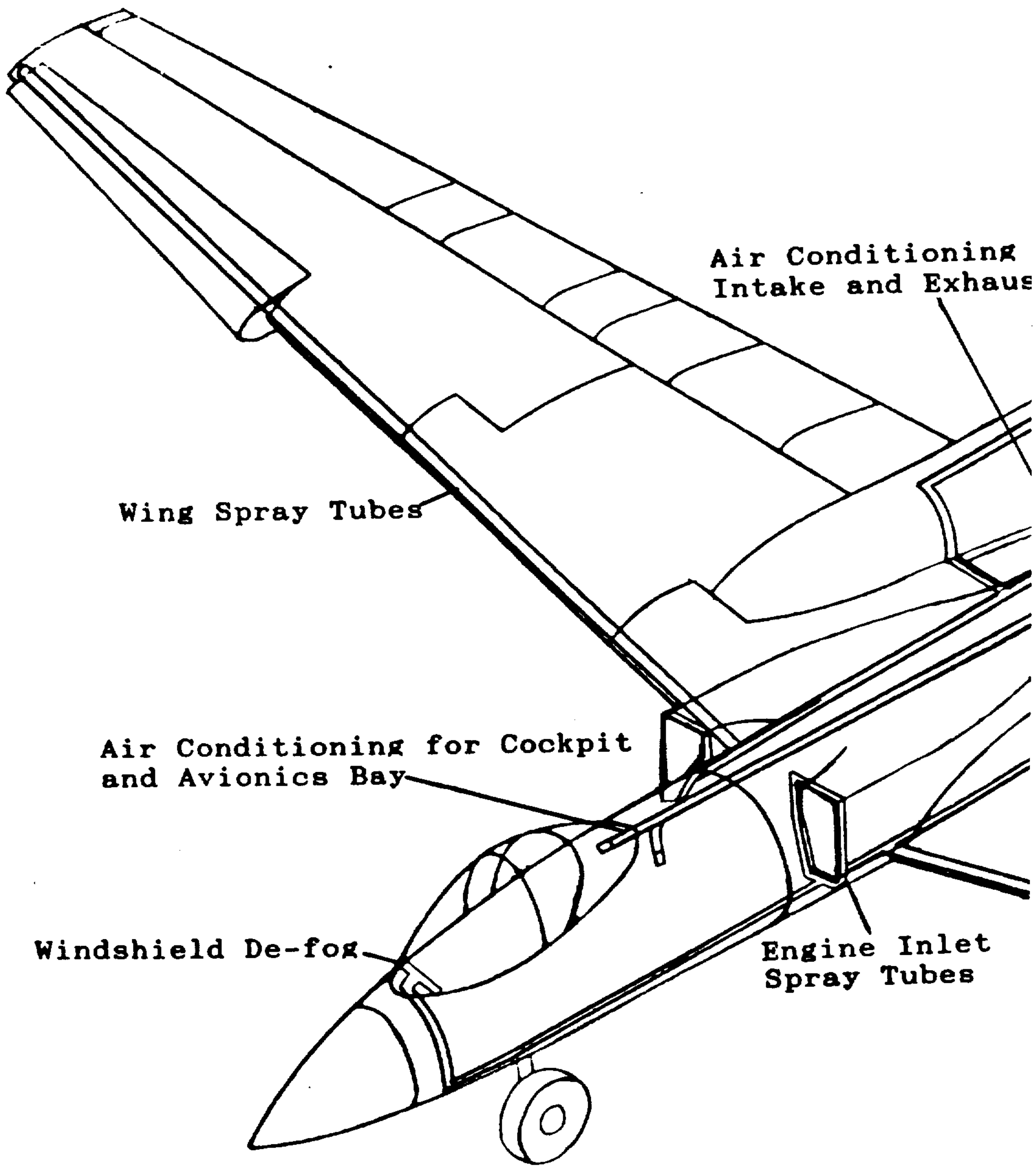
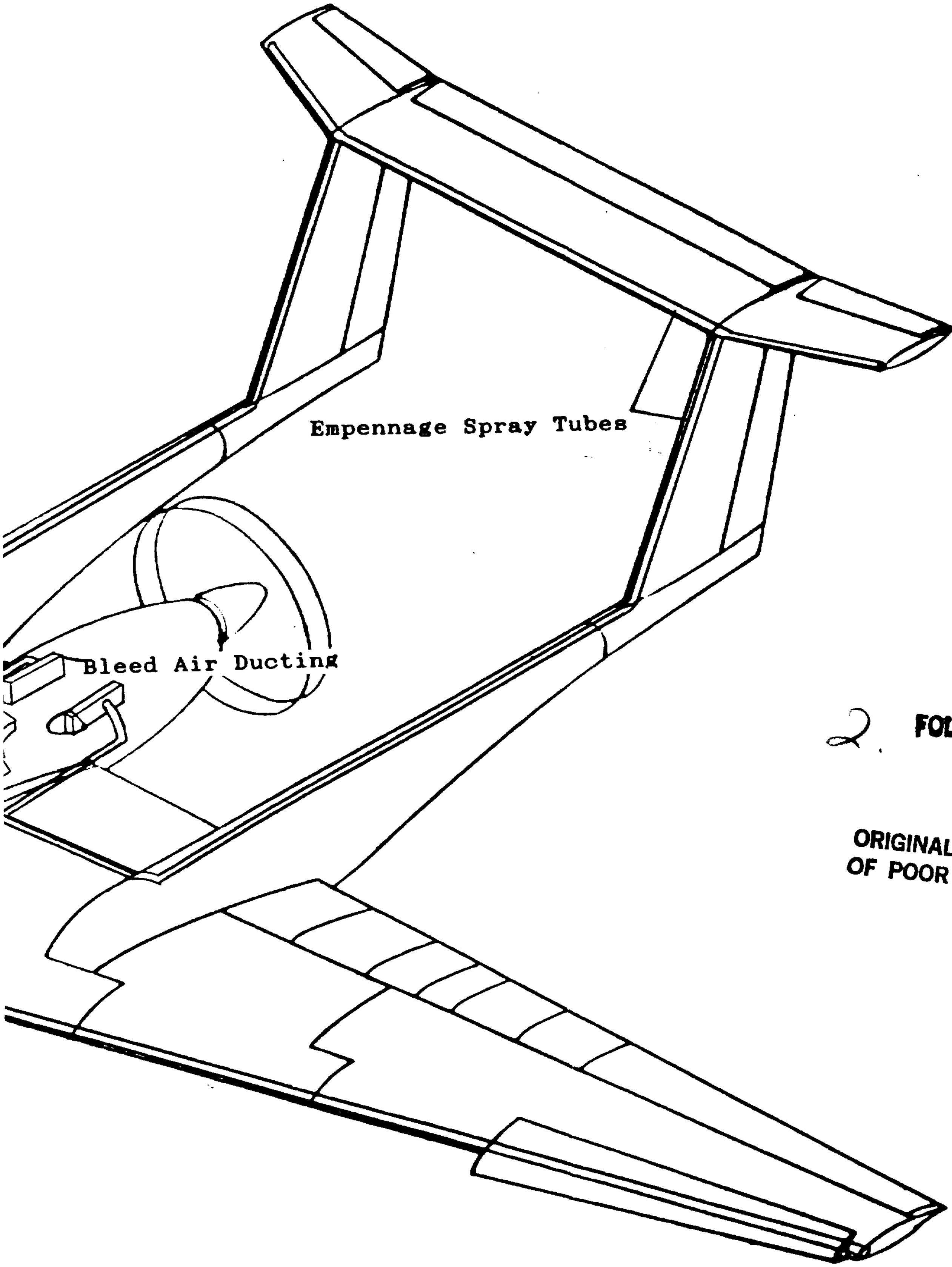


Figure 9.7 The Good: Enviro



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Control and Anti-Ice System Layout

The air conditioning system is required for all three aircraft. Only the Good aircraft, because of its all weather requirement, needs an anti-ice system.

9.6 Internal Armament and Avionics

The internal armament and avionic system layout for the Good is shown in Figure 9.8. The internal armament consists of the GAU-13/A four barrel Gatling gun, its 1200 round ammunition drum, and the passive ECM (chaff/flare) dispensers. The avionics shown consists of the attack radar, mission computer, and the heads-up display. The remaining avionic components are not shown for the sake of clarity. The remaining avionic components are located in two bays. One is directly above the mission computer behind the cockpit instrument panel. The second bay is directly behind the pilot, between the ejection seat and the ammunition drum.

The internal armament arrangement is the same for the Bad and Ugly airplanes except for the size of the ammunition drum (400 rounds instead of 1200). The avionics layout is the same for each aircraft except that the Ugly does not have an attack radar.

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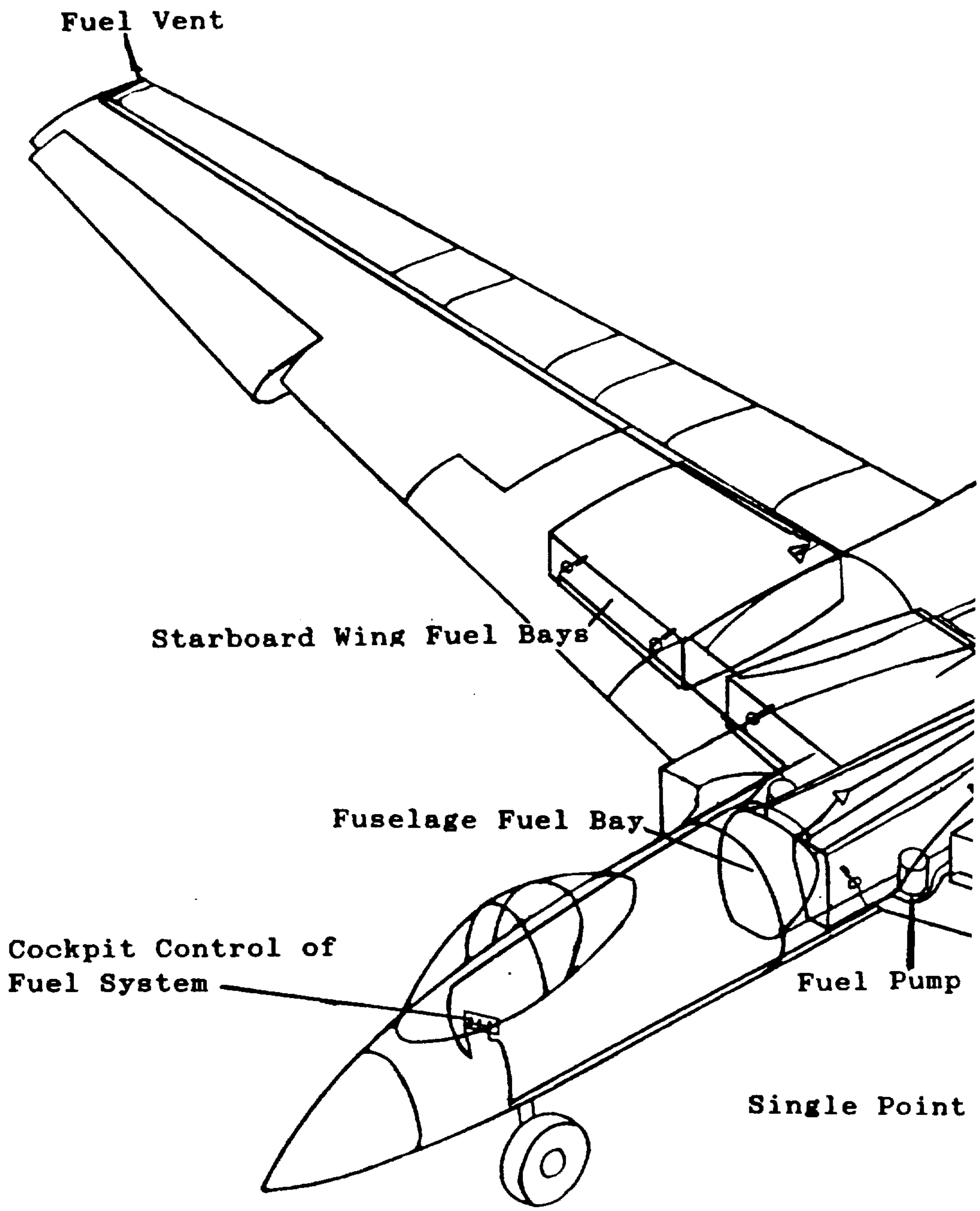
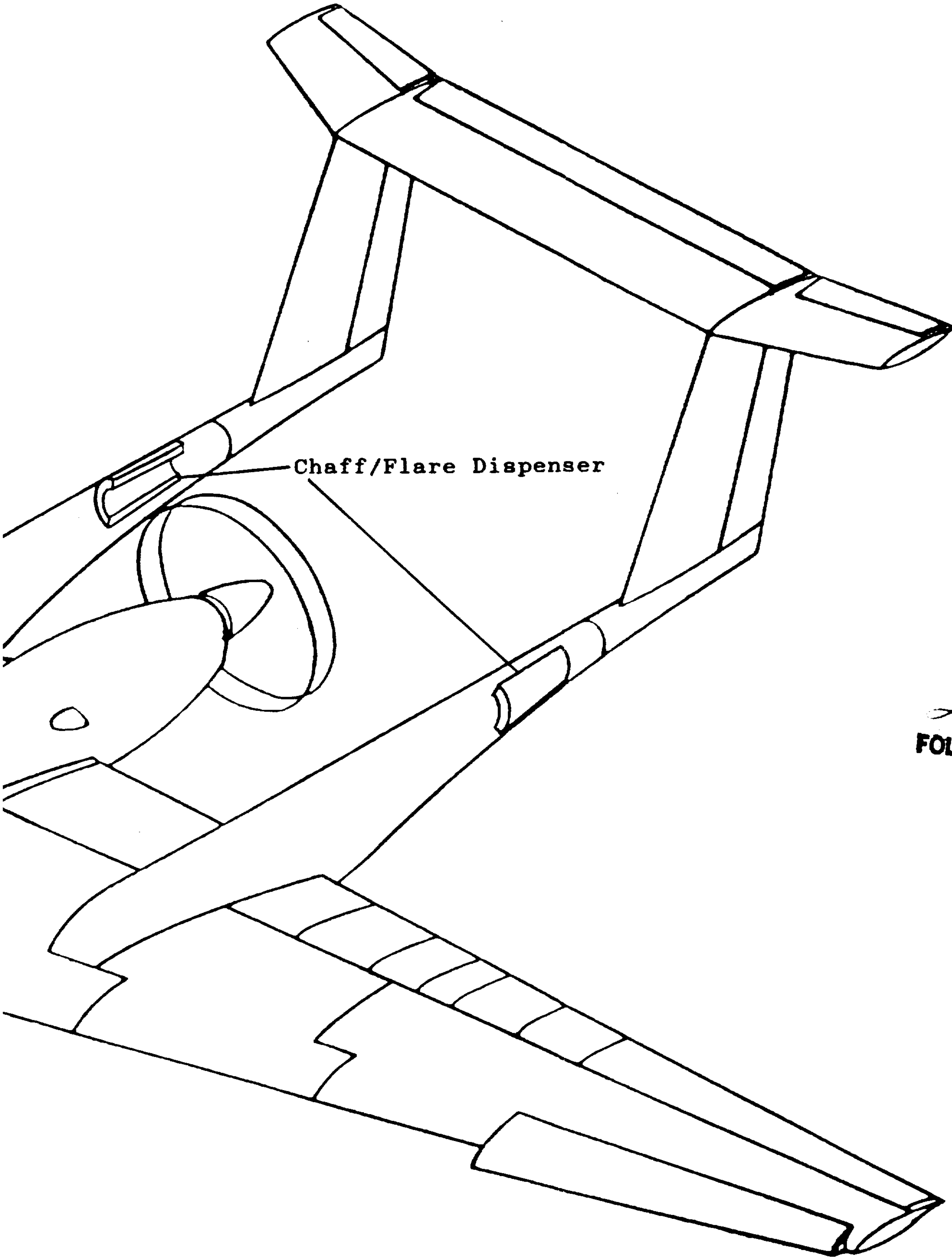


Figure 9.6 Tl



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ment and Avionic System Layout

10. LIFE CYCLE COST

The purpose of this chapter is to present the results of the life cycle costs analysis of the Good, Bad, and Ugly aircraft. The effects of the commonality on the cost of the aircraft is also presented.

The method used to calculate the life cycle costs and the life cycle estimation results are given in Section 10.1. The development, test and evaluation, and acquisition costs are presented in Section 10.1.1. Section 10.1.2 presents the operations and support cost. The effects of commonality on the aircraft costs are shown in Section 10.2.

10.1 Life Cycle Cost Method and Results

The cost estimating method used for the Good, Bad, and Ugly aircraft was taken from Reference 23. This method presents aircraft cost as life cycle cost. The life cycle cost of an aircraft is the total cost required to take the aircraft from its initial conceptual design to retiring it from the fleet. The life cycle cost includes the following phases:

* Research
* Development, Test and Evaluation (DT&E)
* Acquisition (Production)
* Operations and Support

The research phase involves the basic costs required to develop those technologies that are essential to the success of the aircraft. This phase may include technology demonstrator aircraft an testbeds.

The development, test and evaluation cost is that cost needed for engineering work and aircraft development prior to production of and aircraft. The cost elements within DT&E are:

* Airframe engineering
* Development support
* Flight test aircraft
    - Engine and avionics
    - Manufacturing labor
    - Tooling
    - Quality control
* Flight test operations
* Profit

The primary element of acquisition cost is production. Secondary elements of acquisition cost are ground equipment, initial spares, and training aids for the aircraft. The cost elements within acquisition costs are:

* Engine and avionics

* Manufacturing labor
* Manufacturing material
* Airframe engineering (sustaining)
* Tooling
* Quality control
* Profit

Equations (called cost estimating relationships) are given in Reference 23 for each of these elements.

The cost elements within operations and support are the following:

* Fuel
* Maintenance
* Aircrew
* Other
  - Indirect
  - Spares
  - Depot
  - Miscellaneous

Figures 10.1 through 10.3, respectively, show the life cycle cost estimates of the Good, the Bad, and the Ugly aircraft. Table 10.1 shows the dollar values of the life cycle costs. The life cycle cost is based on a fleet of 100 aircraft with a 20 year operating cost. (The DT&E and production cost is based on the unit cost obtained by producing 500 aircraft and the resulting number was multiplied by 1/5 to get the cost of 100 aircraft).

Table 10.1 Life Cycle Costs of the Good, Bad, and Ugly (millions of 1989 dollars)

Note: Based on fleet size of 100 aircraft, operating for 20 years at 300 flight hours/year.

	Total DT&E	Total Production	Operating
Good	26.2	1,074.2	826.4
Bad	16.5	711.1	622.6
Ugly	8.2	290.3	556.9

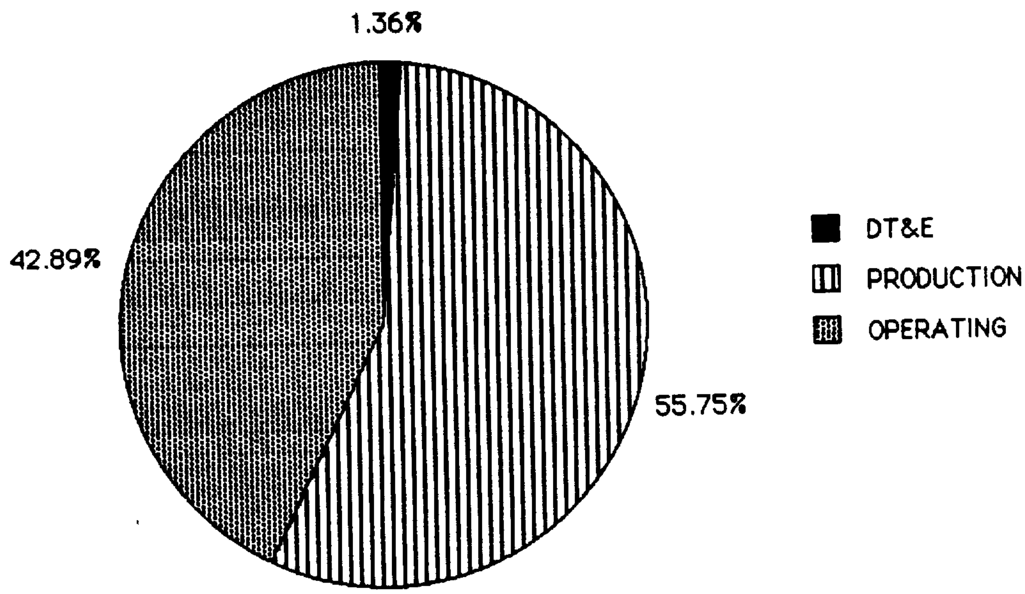

Figure 10.1 The Good: Life Cycle Cost

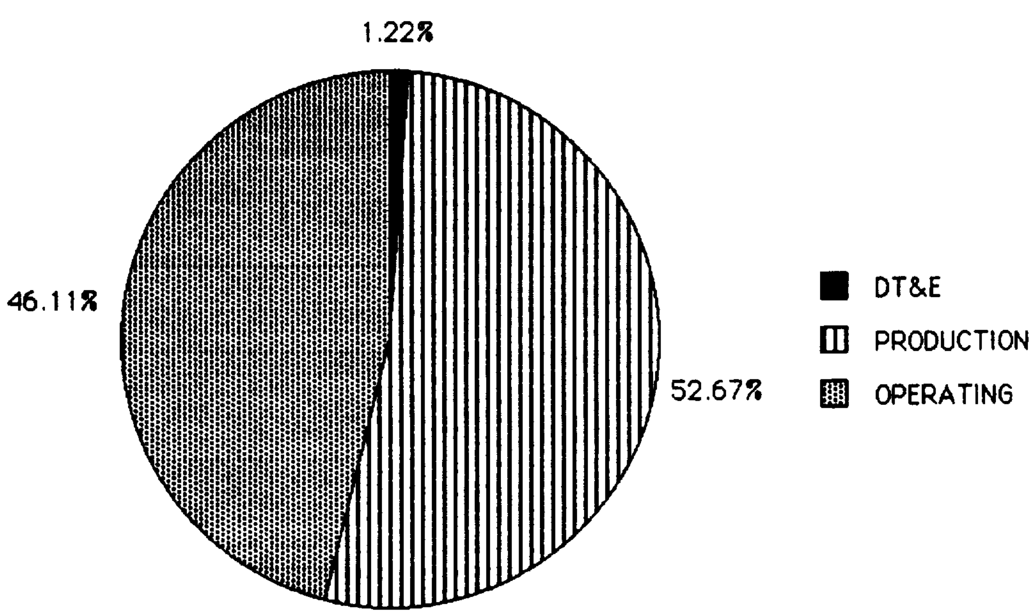

Figure 10.2 The Bad: Life Cycle Cost

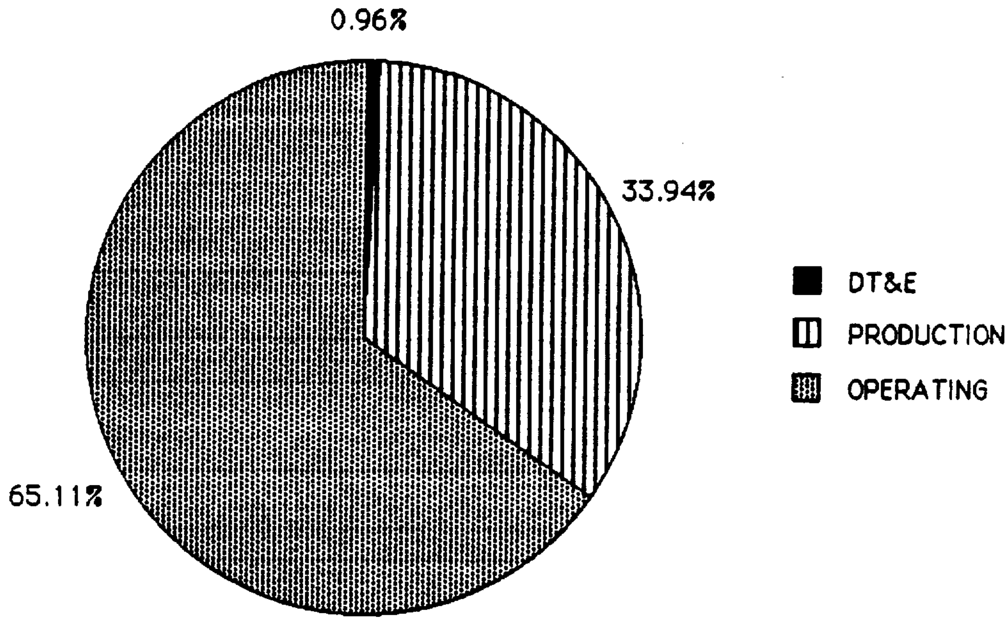

Figure 10.3 The Ugly: Life Cycle Cost

10.1.1 Development, Test and Evaluation and Acquisition Costs

There are six variables in the cost estimating method used which have a large effect on the unit cost of the aircraft. These six variables are:

1) AMPR Weight
2) Quantity of aircraft produced
3) Maximum speed at best altitude
4) Engine cost estimate
5) Avionics cost estimate
6) Labor rates

1) AMPR Weight - The AMPR (Aeronautical Manufacturers Planning Report) weight is defined as the empty weight of the aircraft less 1) wheels, brakes, tires, and tubes, 2) engines, 3) starter, 4) cooling fluid, 5) rubber or nylon fuel cells, 6) instruments, 7) batteries and electrical equipment, 8) electronic and avionic equipment, 9) armament and fire-control system, 10) air conditioning units and fluid, 11) auxiliary power unit, and 12) trapped fuel and oil. The weight and balance statements of Reference 7 were used to calculate the AMPR weight. These calculations are shown in Appendix E and the results are given in Table 10.2.

Table 10.2 Input for the DT&E and Acquisition Costs

	Good	Bad	Ugly
Take-off Weight	39,608	21,833	10,663
Empty Weight	20,609	12,375	6,965
AMPR Weight	12,283	7,377	3,809
AMPR/Empty	0.60	0.60	0.55
Engine SHP	6000	2500	2500
# of Engines	2	2	1
Engine Cost	1,800,000	800,000	800,000

	Good, Bad, and Ugly
Maximum Speed	350 kts
Production Quantity	Variable
Production Rate (per month)	Variable
Flight Test Quantity	3
Flight Test Rate (per month)	1
Labor Rates:	
Airframe Engineering	$ 48.3 per hour
Tooling	$ 34.6 per hour
Manufacturing	$ 26.9 per hour

Avionics (cost per system)	Good	$3,148,345
	Bad	$3,148,345
	Ugly	$948,345

2) Quantity produced - The quantity of aircraft produced is usually dependent upon the fiscal policy and the economic outlook of a country. The results of the unit costs are therefore shown for a range of quantity produced, from 250 to 1000 units.

3) Maximum speed - The maximum speed at best altitude is 350 kts for each aircraft according to the mission specifications of Reference 7.

4) Engine cost - Accurate engine cost estimates are crucial to the aircraft unit cost estimate. Reference 24 was used to get the engine cost for the Good aircraft. The Bad and Ugly engine cost were obtained from Reference 25. The data from these references was plotted and is shown in Figures 10.4 and 10.5. The derivations of the engine costs are shown in Appendix E and the results are given in Table 10.2.

5) Avionics cost - A list of avionic components required for the three aircraft was taken from Reference 7. The cost of these components was first estimated with the help of Reference 26 and 27. The cost estimate was revised using the results of Reference 28. The avionic cost estimation procedure is shown in Appendix E and the results are given in Table 10.2.

6) Labor rates - The labor rates used in the cost model are airframe engineering, tooling, and manufacturing rates. The labor rates were estimated with the help of Figure 10.6 and Reference 23. The 1974 labor rates were taken from Reference 23 and multiplied by the ratio of 1989 to 1974 prices to get the 1989 labor rates. Figure 10.6 was derived using Reference 29 and 30. The 1989 labor rates are shown in Table 10.2.

The results of the DT&E and Acquisition cost estimation are shown in Table 10.3 through 10.5, respectively, for the Good, Bad, and Ugly. These tables show the results of the spreadsheets used to calculate the costs. The entire spreadsheet for each aircraft is shown in Appendix E along with a sample calculation, given to verify the spreadsheets. The results shown in Tables 10.3 through 10.5 show the unit cost when 500 aircraft are produced. Figure 10.7 through 10.9, respectively, shown the unit cost of the Good, Bad, and Ugly aircraft as a function of the quantity produced. Note: all quantities are produced within five years.

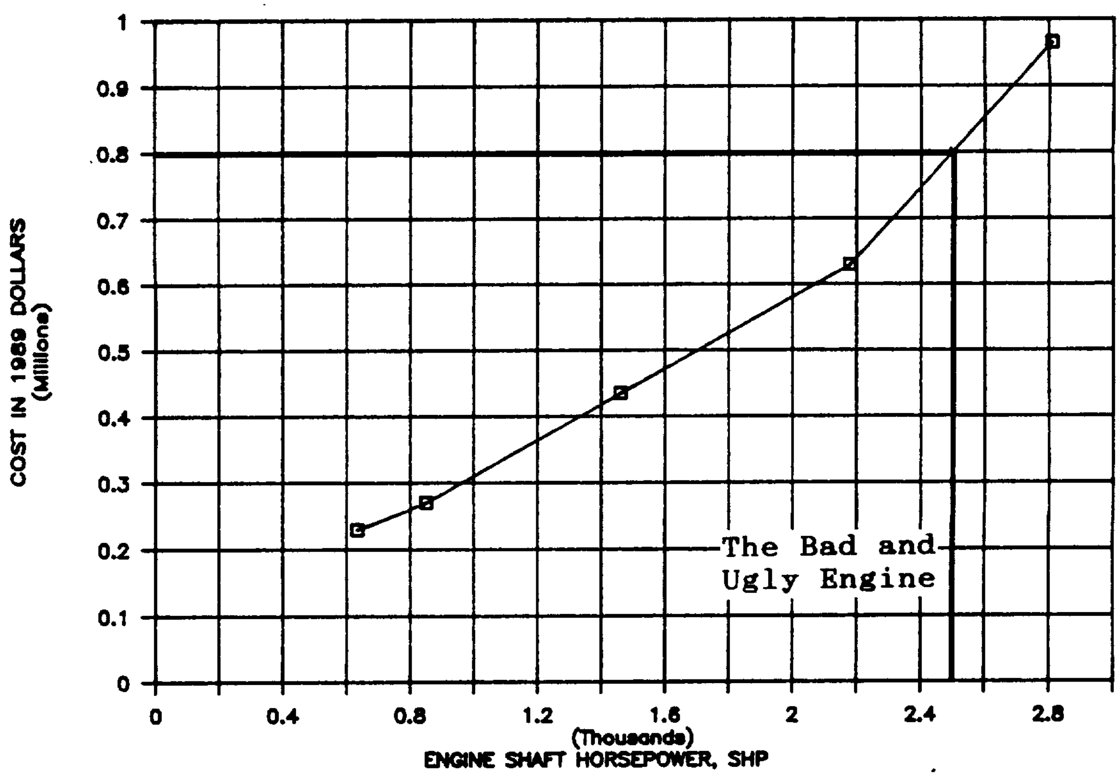

Figure 10.4 Engine Cost as a Function of Engine SHP

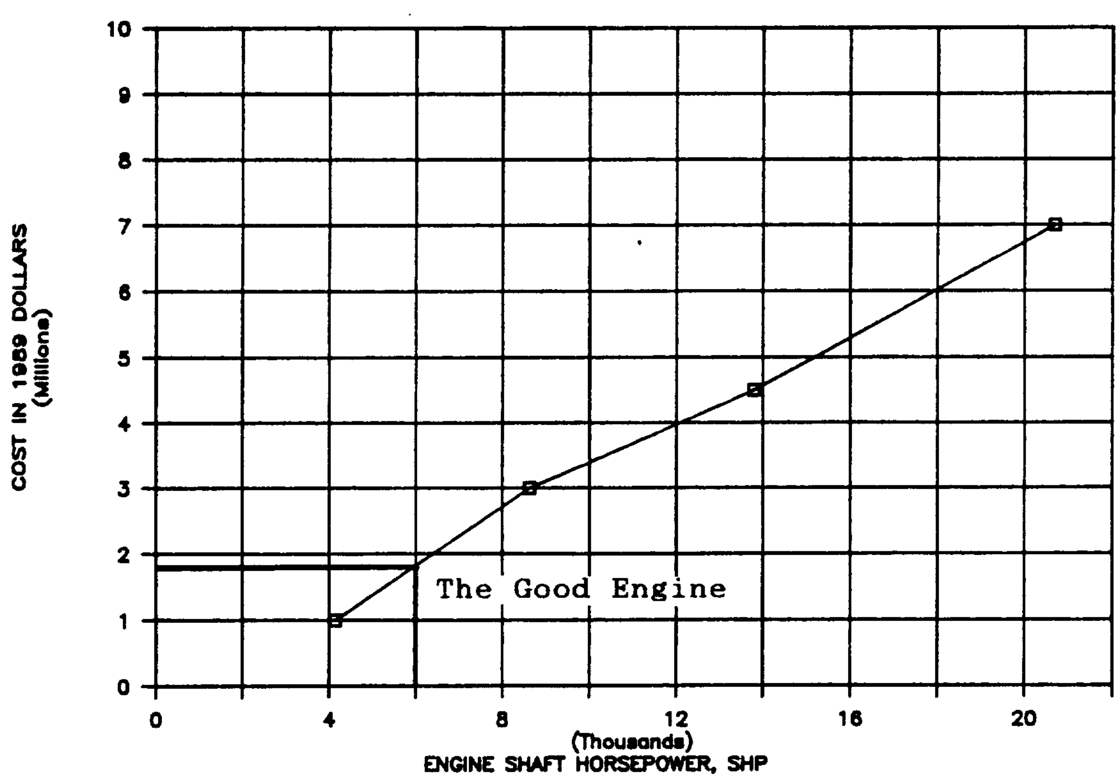

Figure 10.5 Engine Cost as a Function of Engine SHP

Table 10.3 DT&E and Acquisition Costs for the Good (Cost in millions of 1989 dollars)

Total DT&E Cost

Airframe Engineering................		18.3
Development Support.................		4.8
Flight Test Aircraft................		94.2
Engines & Avionics......	24.7	
Manufacturing Labor.....	29.5	
Material & Equipment....	4.0	
Tooling.................	32.2	
Quality Control.........	3.8	
Flight Test Operations..............		1.7
	Subtotal	119.0
	Profit (10 percent of Subtotal)	11.9
	Total DT&E Cost	130.9

Total Production and Unit Cost

Engine and Avionics.................		4113.1
Manufacturing Labor.................		401.3
Material and Equipment..............		227.9
Sustaining Engineering..............		28.4
Tooling.............................		59.8
Quality Control.....................		52.2
	Subtotal	4882.8
	Profit (10 percent of Subtotal)	488.3
	Total Production Cost	5371.1

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.3 million per a/c.

The 1989 unit cost (at 500.0 units) is:

5371.1 / 500.0 + 0.3 = 11.00

Table 10.4 DT&E and Acquisition Costs for the Bad
(Cost in millions of 1989 dollars)

Total DT&E Cost

Airframe Engineering................		12.2
Development Support.................		3.1
Flight Test Aircraft................		58.6
Engines & Avionics......	11.1	
Manufacturing Labor.....	20.2	
Material & Equipment....	2.8	
Tooling.................	21.8	
Quality Control.........	2.6	
Flight Test Operations..............		0.9
	Subtotal	74.9
Profit (10 percent of Subtotal)		7.5
	Total DT&E Cost	82.4

Total Production and Unit Cost

Engine and Avionics.................	2701.5
Manufacturing Labor.................	275.2
Material and Equipment..............	160.4
Sustaining Engineering..............	19.0
Tooling.............................	40.5
Quality Control.....................	35.8
Subtotal	3232.4
Profit (10 percent of Subtotal)	323.2
Total Production Cost	3555.7

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.2 million per a/c.

The 1989 unit cost (at 500.0 units) is:

3555.7 / 500.0 + 0.2 = 7.28

Table 10.5 DT&E and Acquisition Costs for the Ugly
(Cost in millions of 1989 dollars)

Total DT&E Cost

Airframe Engineering................		6.1
Development Support.................		1.4
Flight Test Aircraft................		29.3
Engines & Avionics......	4.5	
Manufacturing Labor.....	10.6	
Material & Equipment....	1.5	
Tooling.................	11.2	
Quality Control.........	1.4	
Flight Test Operations..............		0.3

	Subtotal	37.2
Profit (10 percent of Subtotal)		3.7
	Total DT&E Cost	40.9

Total Production and Unit Cost

Engine and Avionics.................		1037.9
Manufacturing Labor.................		144.5
Material and Equipment..............		88.1
Sustaining Engineering..............		9.5
Tooling.............................		20.8
Quality Control.....................		18.8

	Subtotal	1319.6
Profit (10 percent of Subtotal)		132.0
	Total Production Cost	1451.5

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.1 million per a/c.

The 1989 unit cost (at 500.0 units) is:

1451.5 / 500.0 + 0.1 = 2.98

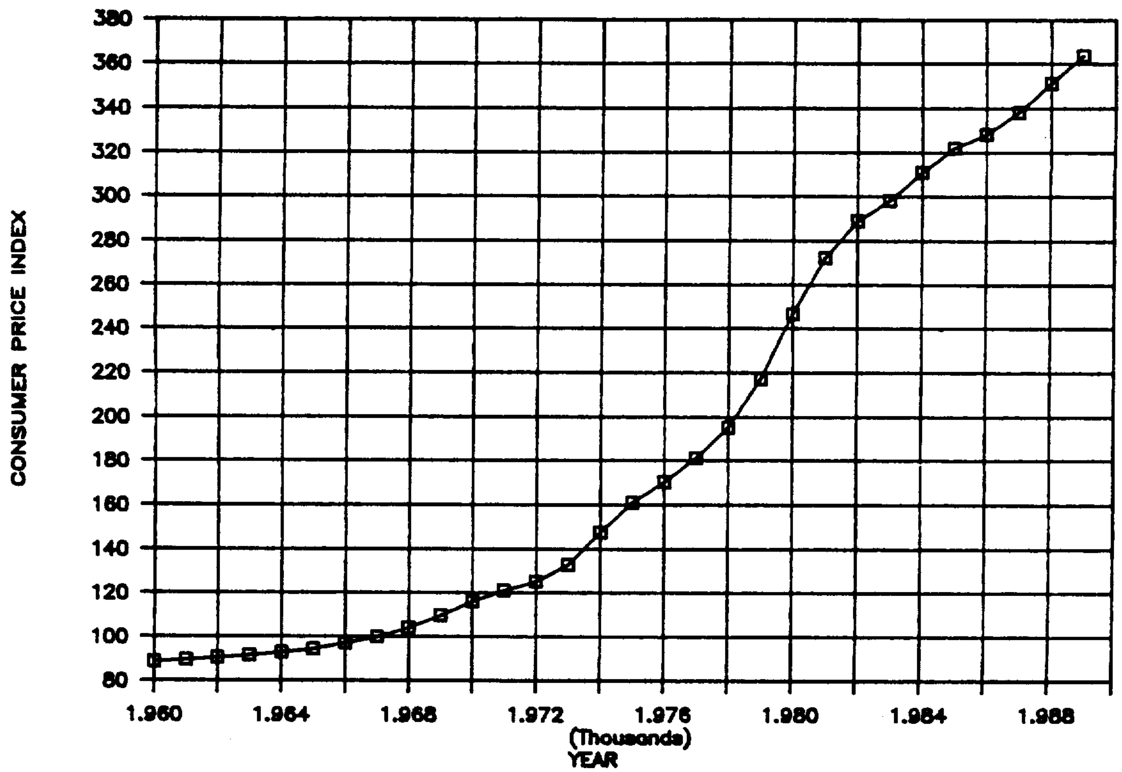

Figure 10.6 Consumer Price Index (1960 - 1989)
Derived from References 29 and 30

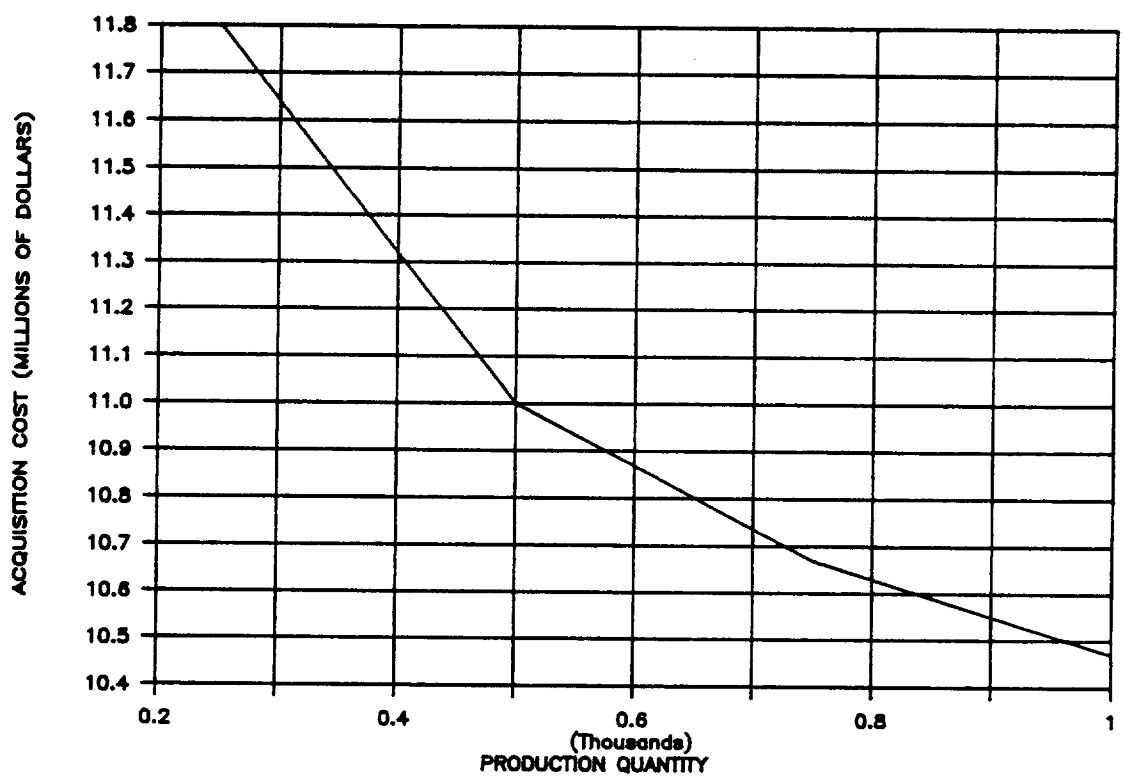

Figure 10.7 The Good: Unit Cost as a Function of
Quantity Produced

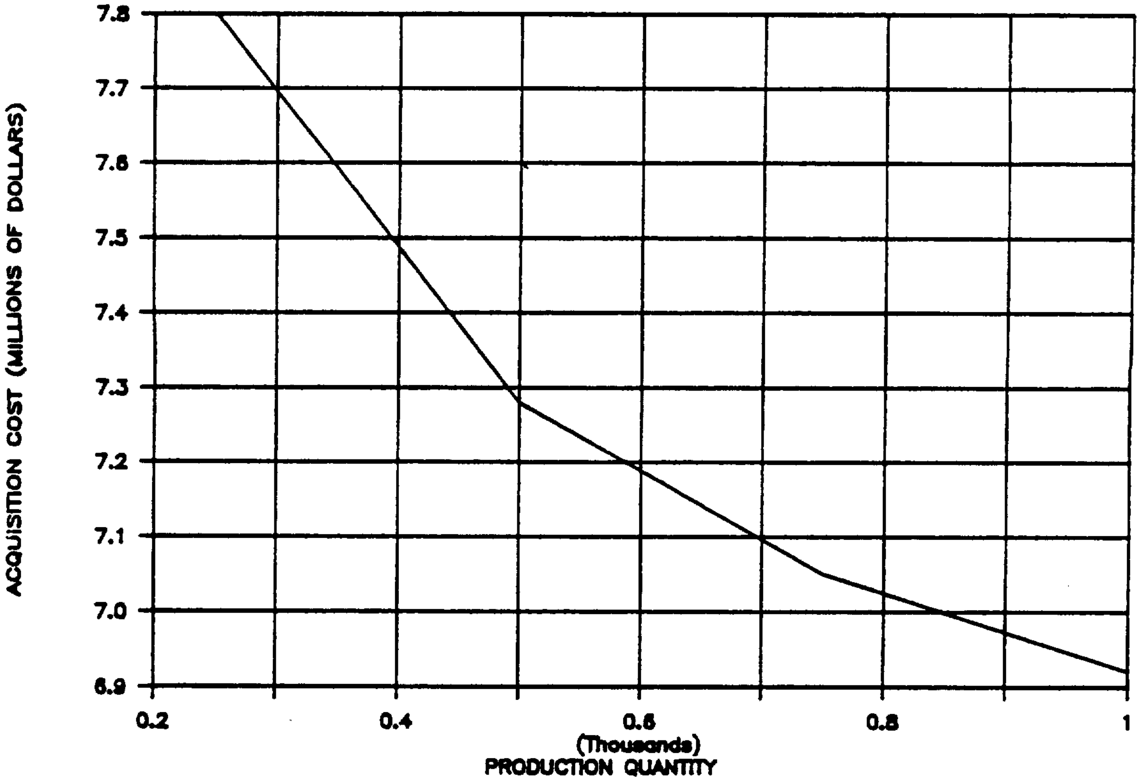

Figure 10.8 The Bad: Unit Cost as a Function of Quantity Produced

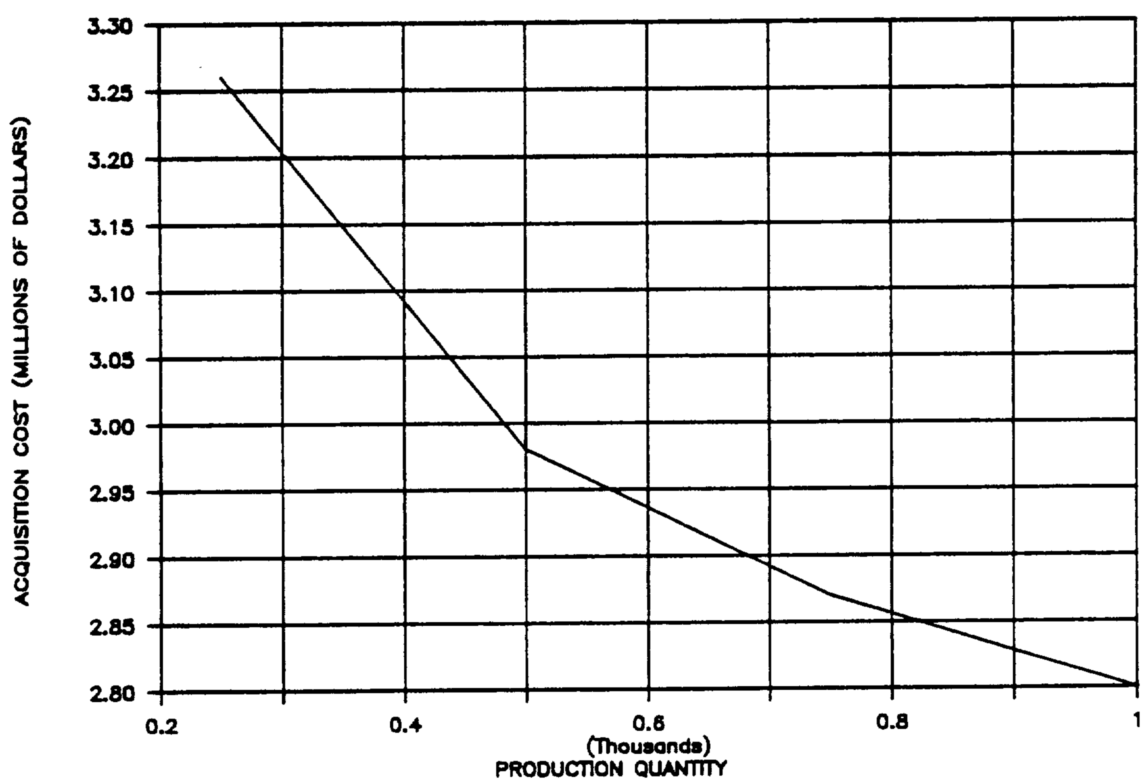

Figure 10.9 The Ugly: Unit Cost as a Function of Quantity Produced

10.1.2 Operations and Support Cost

Reference 23 gives a method for calculating the fuel, maintenance, and aircrew yearly operating costs. The method for calculating the other yearly operating costs was derived using Figure 10.10 (taken from Reference 23). The derivations are shown in Appendix E along with a sample calculation to verify the operations and support spreadsheet. The spreadsheet, Table 10.6, shows the results of the operating and support cost estimation.

Table 10.6 Operations and Support Costs for the Good, Bad, and Ugly Airplanes

*****
Input
*****

Fleet Size = 100

		Good	Bad	Ugly
Fuel:	Engine BSFC at cruise =	0.38	0.38	0.38
	Engine SHP at Cruise =	5100	2000	1000
	Fuel Cost/Gallon =	0.85	0.85	0.85
	Fuel Density (JP-4) =	6.55	6.55	6.55
Crew:	Aircrew Cost/Hour =	26.06	26.06	26.06
	Crew Flight Hours/Year =	500	500	500
	Crew Ratio =	1.1	1.1	1.1
Maint.:	Flight Hours/Aircraft =	300	300	300
	MMH/FH =	10	10	10
	Maint. Cost/Hour =	32.06	32.06	32.06

****
Cost Estimation
****

	Good	Bad	Ugly
(per year per aircraft)			
Fuel Cost	75449	29588	14794
Crew Cost	14333	14333	14333
Maintenance Cost	96180	96180	96180
Other Cost	227245	171203	153125
Cost/Year/Aircraft	413207	311304	278432
Fleet Cost/Year	41320724	31130394	27843191

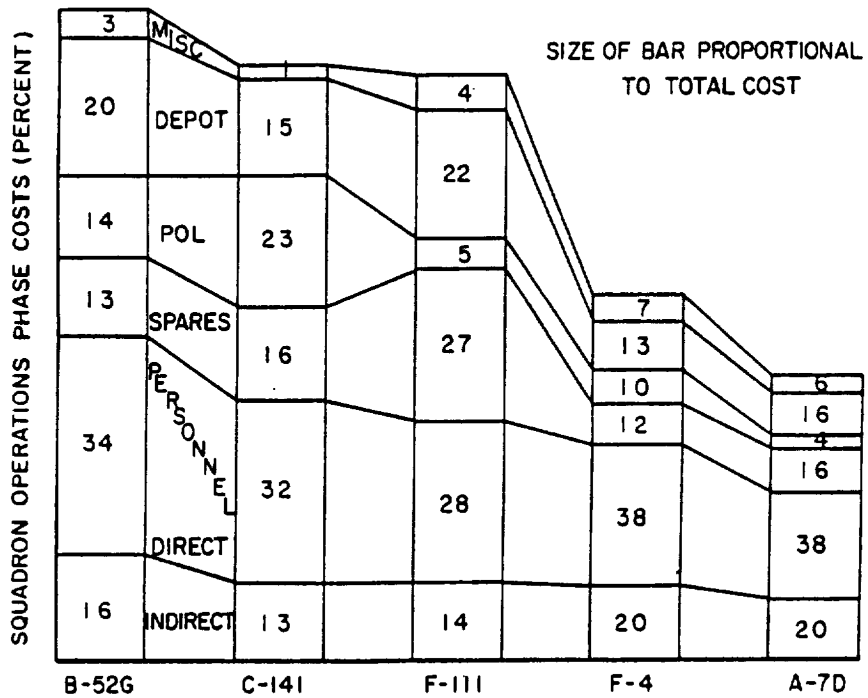

Figure 10.10 Operations Cost for USAF Fighter, Bomber, and Transport Aircraft (Taken from Reference 23)

10.2 Effects of Commonality

The effects of commonality on the cost of the Good, the Bad, and the Ugly were studied for the DT&E and Acquisition cost. The method used was based on determining a common weight among the three aircraft. Appendix E explains the method used.

The results of the commonality study are shown in Figures 10.11 through 10.13. These figures show the non commonality and commonality cost for each aircraft as a function of the quantity produced. Figure 10.14 shows the cost savings for each aircraft also as a function of the quantity produced. The cost savings incurred by having common aircraft were not as favorable as desired. The results, however, may be due to the method used to calculate the effects of commonality. A much more detailed cost analysis should be done before any definite conclusion can be made about the cost savings due to commonality.

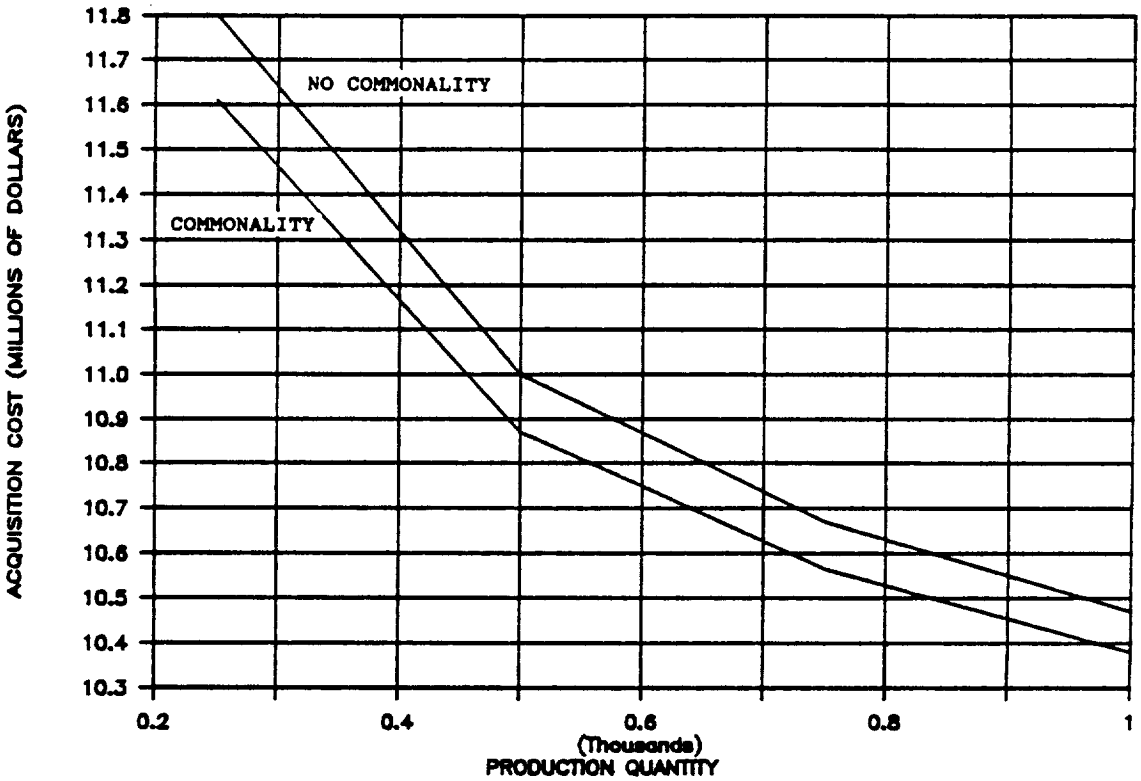

Figure 10.11 The Good: Effects of Commonality on Acquisition Costs

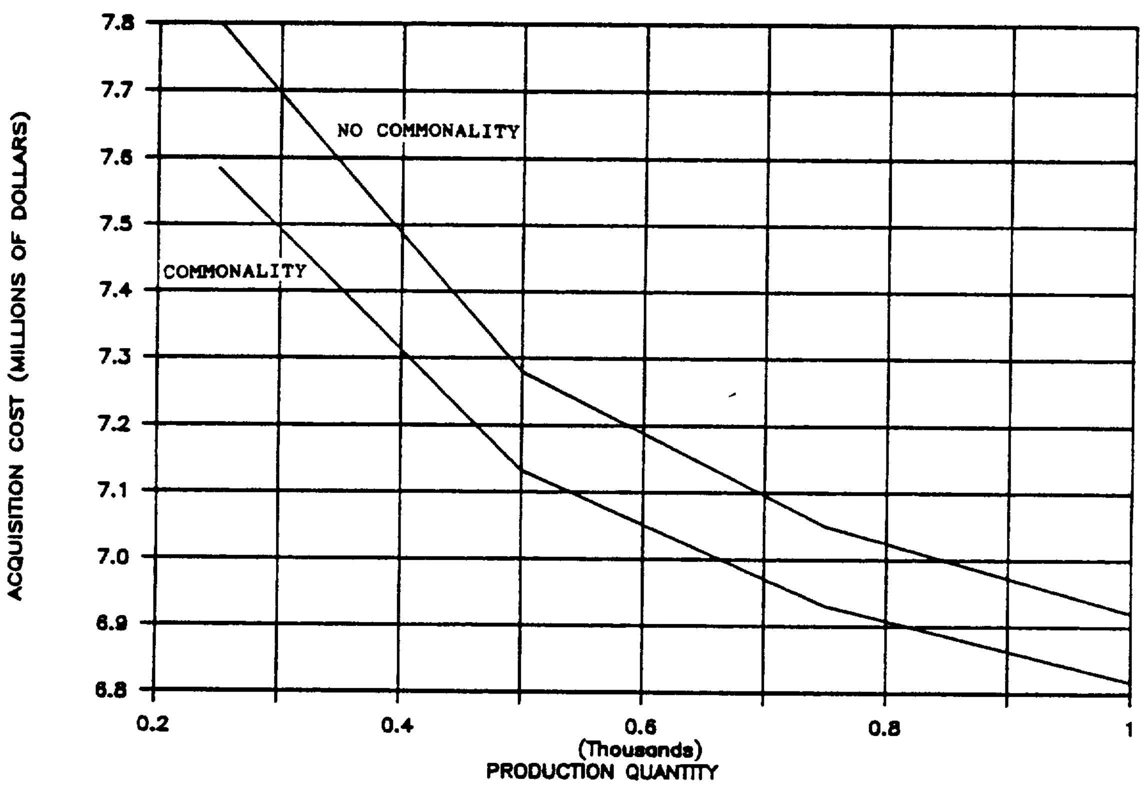

Figure 10.12 The Bad: Effects of Commonality on Acquisition Costs

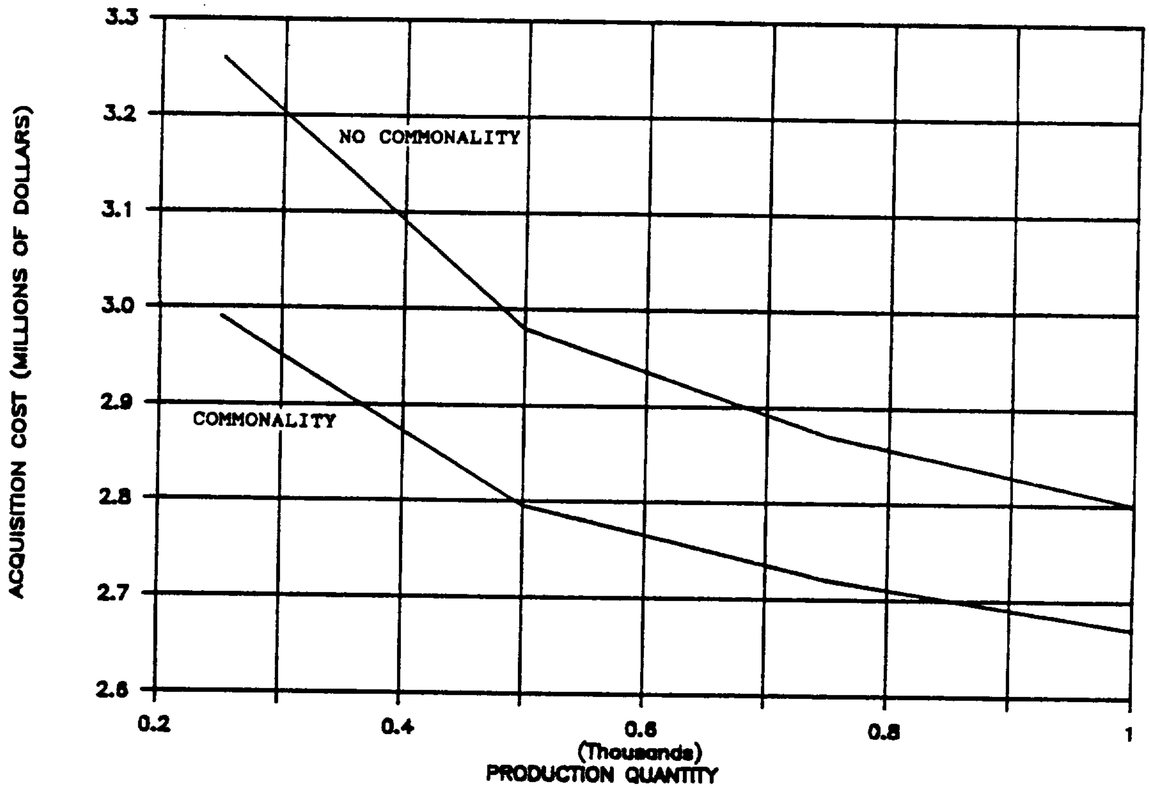

Figure 10.13 The Ugly: Effects of Commonality on Acquisition Costs

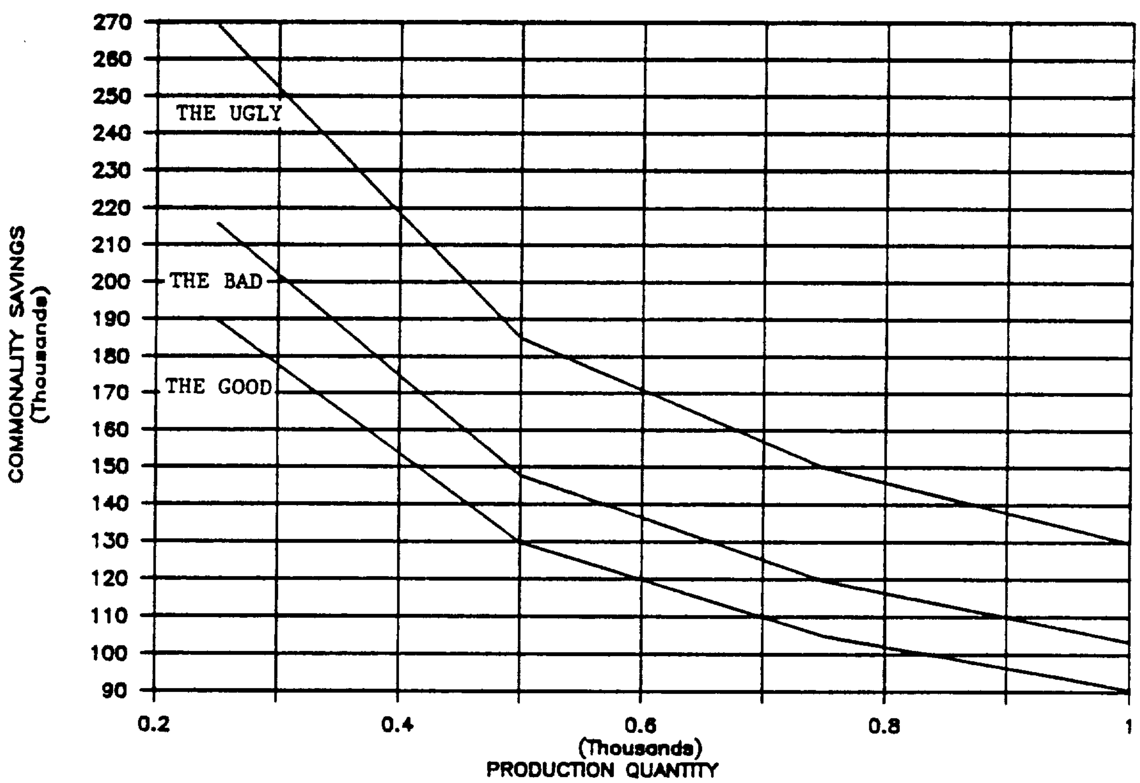

Figure 10.14 Comparison of Cost Savings Due to Commonality

11. COST AND PERFORMANCE COMPARISON

The purpose of this chapter is to compare the cost and performance of the Good, Bad and Ugly airplanes to that of other aircraft with similar mission profiles.

11.1 Performance Comparison

The following aircraft were selected to establish a comparison between the Good, Bad and Ugly and aircraft currently in service:

1) Fairchild Republic A-10
2) FAMA IA 58 Pucara
3) Sukhoi Su-25 Frogfoot
4) AMX
5) Douglas A-1 Skyraider
6) Piper PA/48 Enforcer
7) McDonnell Douglas AH-64 Apache

The Apache helicopter was included in this list as a point of reference of the capability of helicopters and because its mission profile is similar to that of the Bad airplane. The results are listed in Table 11.1. The armament and payload carrying capability comparison are presented separately in Section 11.1.1. Figures 11.1 through 11.7 show the three-views of the airplanes listed above. Section 11.1.2 discusses the results of the comparison between the Good, Bad and Ugly and other aircraft with similar missions.

11.1.1 Armament Comparison

1) Good

* One internal GAU-13/A 30mm Gatling Gun
* Total payload of 10,000 lbs including 1,200 rounds of anti-armor shells, laser and infrared guided weapons, free-fall munitions, and rocket pods.

2) Bad

* One internal GAU-13/A 30mm Gatling Gun
* Total payload of 4,100 lbs, including 400 rounds of anti-armor shells, laser and infrared guided weapons, free-fall munitions and rocket pods.

3) Ugly

* One internal GAU-13/A 30mm Gatling Gun
* Total payload of 2,000 lbs, including 400 rounds of anti-armor shells, free-fall munitions and rocket pods.

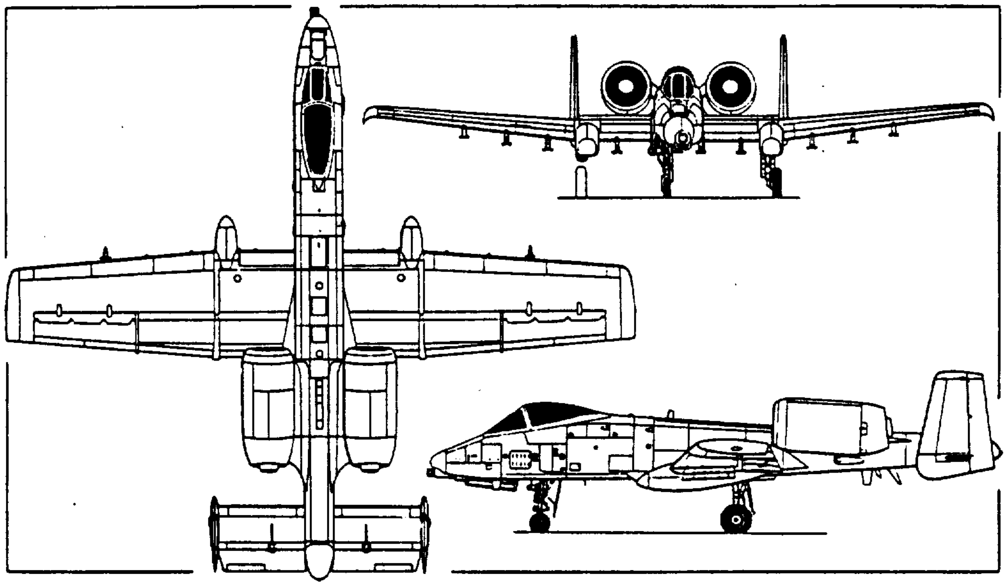

Figure 11.1 Fairchild Republic A-10

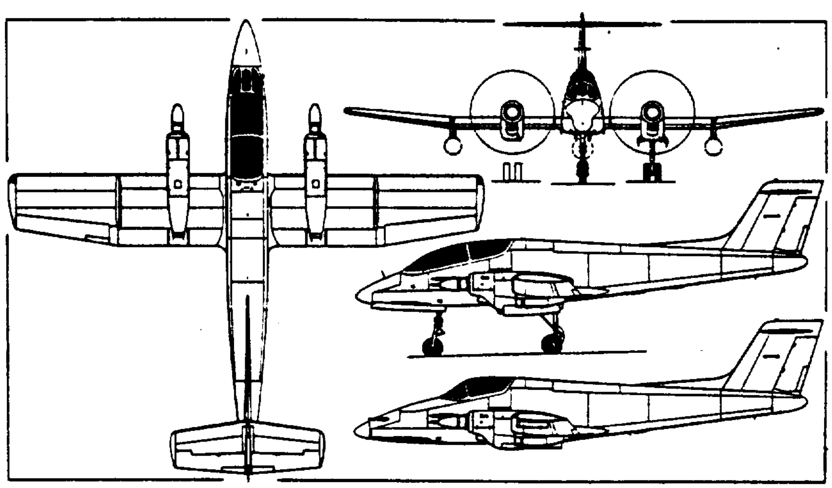

Figure 11.2 FAMA IA 58 Pucara

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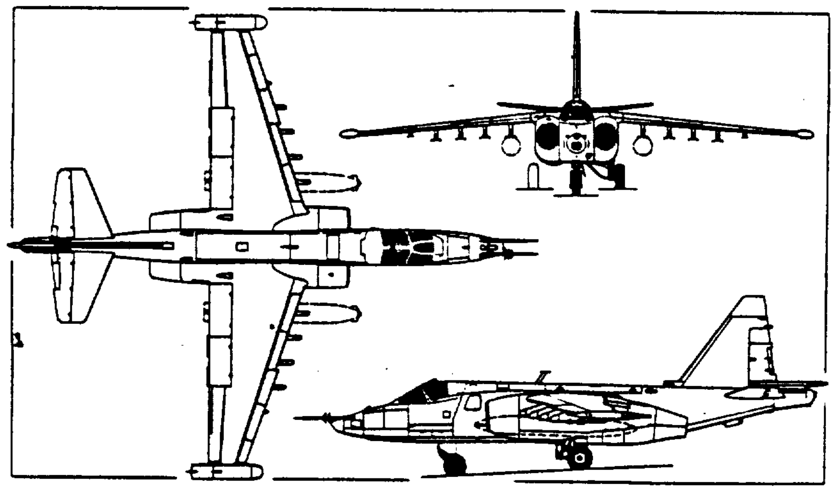

Figure 11.3 Sukhoi Su-25 Frogfoot

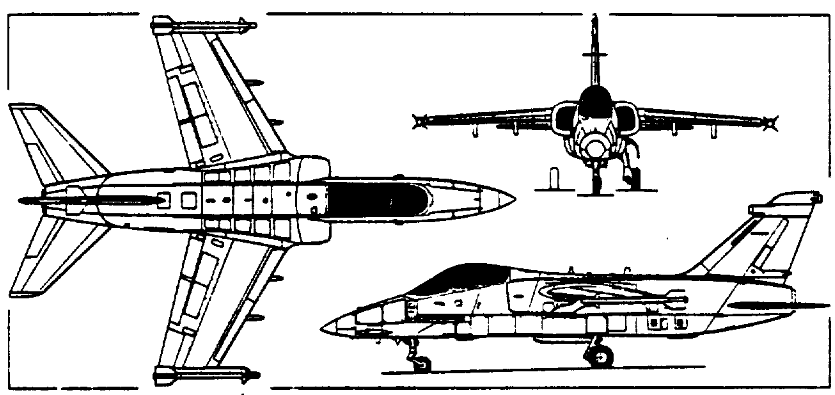

Figure 11.4 AMX

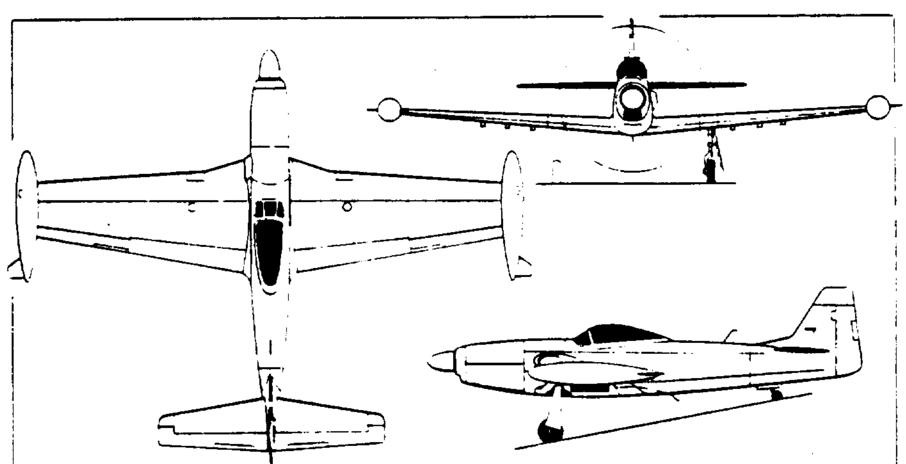

Figure 11.5 Piper PA/48 Enforcer

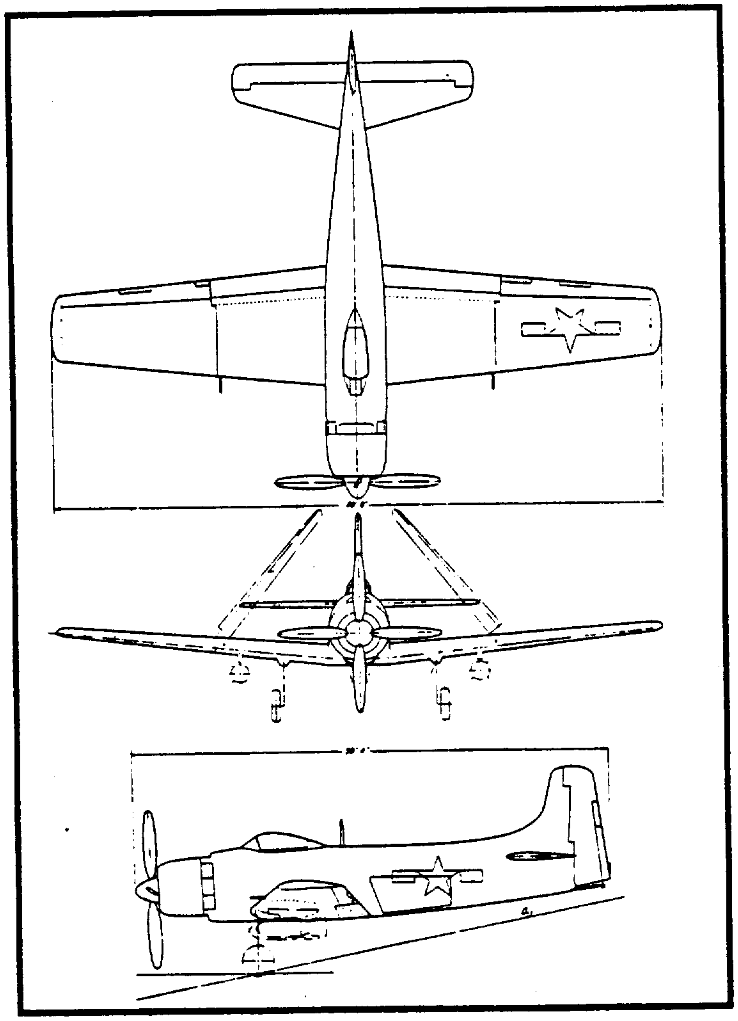

Figure 11.6 Douglas A-1 Skyraider

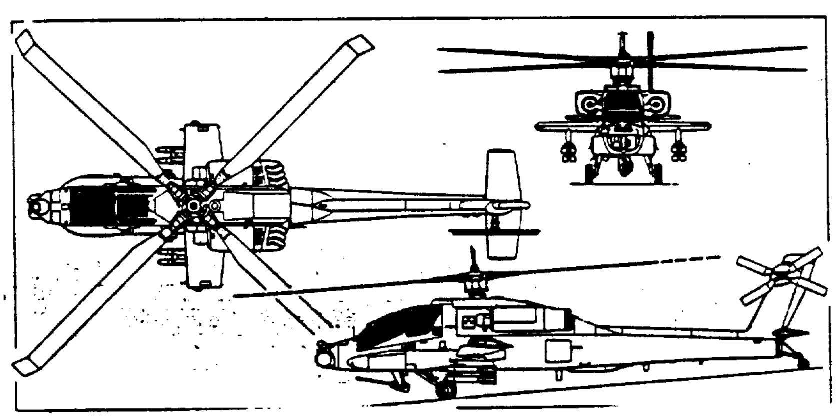

Figure 11.7 McDonnell Douglas AH-64

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4) A-10

* One GAU-8/A 30mm Gatling Gun
* Total payload of 14,638 lbs, including 1,174 rounds of ammunition, laser and infrared guided weapons, and free-fall munitions.

5) Pucara

* Two 20 mm Hispano DCA-804 cannon, with 270 rounds, four 7.62mm Browning M2-30 machine guns with 900 rounds
* Total external load of 3,307 lbs including rocket pods, bombs, mines and torpedoes.

6) Frogfoot

* One twin barrel 30 mm gun
* An estimated total payload of 9,920 lbs of air-to-ground weapons, and two air-to-air self-defense missiles.

7) AMX

* One M61A1 20 mm cannon with 350 rounds
* A total external load of 8,377 lbs including free-fall bombs, air-to-ground missiles, and rocket launchers.

8) A-1 Skyraider

* Four 20 mm cannon in wings with 800 rounds
* A total external load of 9,000 lbs, including torpedo, bombs and rocket launchers.

9) Piper Enforcer

* Two GAU 5/A 30 mm gun pods with 350 rds/gun
* Up to 5,680 lbs of external weapons including free fall munitions and rocket launchers.

10) Apache

* One M230 Chain 30 mm cannon with 1,200 rounds.
* A total of 1,700 lb of external stores including rockets and air-to-ground missiles.

11.1.2 Summary of Performance and Payload Comparison

1) Good. Aircraft that have similar missions to the Good are the A-10, the AMX, and the Frogfoot. The Good compares favorably to all, as shown in Table 11.1. Although slower than the Frogfoot

and the AMX, the Good has twice the combat radius of both the A-10 and Frogfoot. Furthermore, it has similar endurance to the A-10 while having half the take-off and landing groundrun. In terms of armament, the Good and A-10 have similar cannons and carry approximately the same amount of ammunition. The cannon on the Frogfoot is believed to be less capable. The A-10 carries 5,000 lbs of payload more than the Good and Frogfoot.

2) Bad. The A-1 and Pucara have similar mission profiles to the Bad airplane. The Bad has a 10% higher maximum speed than the Pucara and a 30% higher speed than the A-1. The combat radii for the Bad and Pucara are in the 170-190 nm range while the A-1 has a substantially higher maximum combat radius. The Bad has a slightly longer endurance than the A-1, but requires approximately 12% more runway for take-off and landing than the Pucara. The
A-1 carries twice the payload of the Bad and the Pucara, though the GAU-13/A cannon is more effective than the cannon on either airplanes.

3) Ugly. The Ugly and the Piper Enforcer are very similar in terms of mission profiles. Both have approximately the same maximum speed, though the Enforcer has more than 39% greater range. However, the take-off and landing groundruns for the Ugly are in the range of 40% less. The Enforcer carries over twice as much payload as the Ugly, though the GAU-13/A is considered to be more effective than the GAU-5/A. As a point of comparison, the Apache carries approximately the same payload as the Ugly.

Table 11.1 Performance Comparison between CAS Aircraft

	1	2	3	4	5	6	7	8	9	10
Good	20,726	39,725	10,000	364	560	1.3	34,300	1,810	1,130	10.9
Bad	12,791	22,289	4,100	299	168	5.2	31,000	1,120	816	7.1
Ugly	7,517	10,935	2,000	281	157	3.4	32,500	710	560	2.8
A-10	24,918	50,000	14,638	368	250	1.8	2.0	4,000	2,000	7.5
Pucara	10,022	14,991	3,307	270	189	---	32,800	985	656	---
Frogfoot	20,950	42,330	9,920	530	300	---	---	---	---	---
AMX	14,770	27,558	6,377	550	280	---	42,600	2,461	2,400	---
A-1	10,550	25,000	9,000	216	1,300	4.0	25,000	---	---	---
Enforcer	7,885	14,000	5,680	300	400	---	25,000	1,730	1,580	---
AH-64	10,760	21,000	1,700	160	260	3.2	21,000	0	0	9.8

Note:

1) Operational Weight Empty, (lbs)
2) Take-off Weight, (lbs)
3) Payload Weight, (lbs)
4) Maximum Speed, (kts)
5) Combat Radius, (nm)
6) Endurance, (hrs)
7) Combat Ceiling, (ft)
8) Take-off Groundrun, (ft)
9) Landing Groundrun, (ft)
10) Cost in Millions of Dollars (1989)

11.2 Cost Comparison

The following two aircraft are included in the cost comparison:

1) Fairchild Republic A-10
2) McDonnell Douglas AH-64 Apache

The cost for these aircraft were found in References 31 and 32, respectively.

Table 11.2 shows the 1989 acquisition cost for the above two aircraft and for the Good, Bad, and Ugly. The Good, Bad, and Ugly costs are based on a unit cost of producing 500 aircraft. The A-10 cost is based on its 1977 acquisition cost corrected to 1989 dollars using the consumer price index. The AH-64 cost is based on the quantity produced as of 1989 (675 units according to Reference 32).

Table 11.2 Cost Comparison for the Good, Bad, and Ugly

Aircraft	Cost millions of 1989 dollars
The Good	10.9
The Bad	7.1
The Ugly	2.8
Fairchild A-10	7.5
Apache AH-64	9.8

From Section 11.1, the following aircraft can be compared to each other on a mission profile basis and thus will be compared to each other from a cost point of view:

* The Good vs. the A-10
* The Ugly vs. the AH-64

The Good airplane is 3.4 million dollars more expensive than the A-10. The Ugly and the Apache carry approximately the same payload while the Ugly costs 7 millions dollars less than the Apache.

12 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of the preliminary design of the family of Close Air Support aircraft are presented in this chapter.

12.1 Conclusions

1) A family of three CAS aircraft were taken through preliminary design and at this stage they seem viable.

2) Commonality was achieved in the following areas:
   * Forward fuselage
   * Propulsion system
   * Landing gear
   * Wing
   * Weapons system
   * Empennage

3) The weights of the aircraft, including penalties due to commonality, were calculated. The aircraft have acceptable center of gravity travels.

4) The aircraft meet all the performance requirements and have comparable performance characteristics with other CAS aircraft.

5) The handling qualities for the Good aircraft were calculated. The Good aircraft is Level 1 except for a couple of instances. Aerodynamic redesign or stability augmentation could be used to bring the aircraft to Level 1 for all flight conditions.

6) A preliminary structural arrangement was laid out. The wing components were sized for the Good aircraft. Advanced materials were used where possible to reduce weight.

7) The flight control, hydraulic, electrical, environmental control and anti-ice, and internal weapon systems were arranged in the aircraft. At this point there is not a space conflict among the systems.

8) The life cycle cost of the aircraft was estimated for the three aircraft. The cost savings due to commonality were also estimated. The Good, Bad, and Ugly aircraft are affordable, with acquisition costs of $10.9, $7.1, and $2.8 million, respectively.

12.2 Recommendations

1) More studies should be performed to predict the success of the Good, Bad, and Ugly aircraft in the modern battlefield.

2) The structural components should be sized so that better weight estimates can be obtained. This would also enable better prediction of the weight penalties due to commonality.

3) A study needs to be conducted to determine if either aerodynamic redesign or stability augmentation should be used to get the handling qualities to Level 1 in all flight conditions.

4) The components of the individual systems need to be sized to ensure that a space conflict does not exist among the systems.

5) The flutter analysis needs to be corrected. The wing of the Good aircraft seems that it may be prone to flutter and possibly invalidate the design. The flutter analysis should be given high priority.

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APPENDIX A

The purpose of this appendix is to present the calculations done to determine the weight and balance for the Good, Bad and Ugly. Calculations of the moments of inertia for the three airplanes are also presented.

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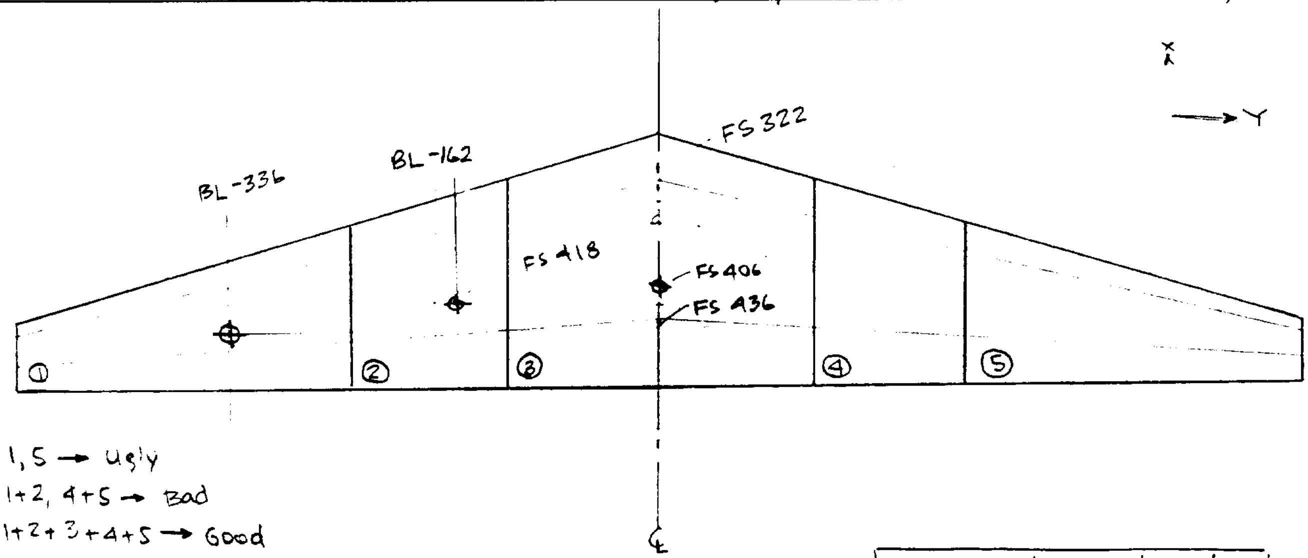
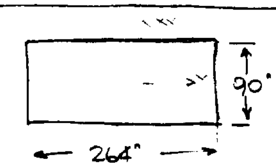


1, 5 → Ugly
1+2, 4+5 → Bad
1+2+3+4+5 → Good

• Inertia calculation : (About own axis)

Approximated by rectangular prisms. (constant thickness)



Section ① & ⑤: $m = 917\,lb/2 = 458.5\ lb$

$$I_{xx} = \frac{1}{12}\frac{(458.5)[264^2]}{2(32.17)(144)}$$

$$I_{xx} = 287.4\ slug \cdot ft^2$$

NOTE: All wing inertia calculations are for each section.

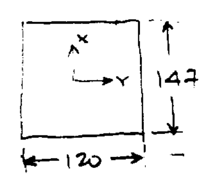
$$I_{yy} = \frac{1}{2}\frac{(458.5)(90^2)}{(12)(32.17)(144)}$$

$$I_{yy} = 33.3\ slug \cdot ft^2$$

$$I_{zz} = \frac{1}{2}\frac{(458.5)(90^2 + 264^2)}{(12)(32.17)(144)}$$

$$I_{zz} = 320.8\ slug \cdot ft^2$$

Section ② & ④ $m = 1{,}419\,lb/2 = 709.5\ lb$



$$I_{xx} = \frac{(709.5)[120^2]}{12(32.17)(144)} = 183.8\ slug \cdot ft^2$$

$$I_{yy} = \frac{(709.5)(147^2)}{12(32.2)(144)} = 275.8\ slug \cdot ft^2$$

$$I_{zz} = \frac{(709.5)(120^2 + 147^2)}{12(32.2)(144)} = 459.6\ slug \cdot ft^2$$

section ③ $m = 2944\,lbs/2 = 1472\ lb$

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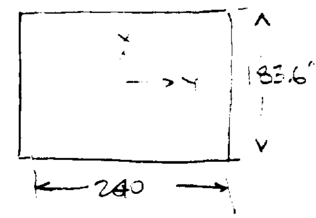
"GOOD"

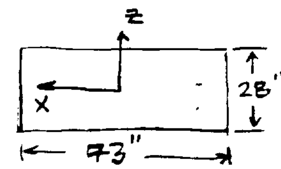
$$I_{xx} = \frac{2(1472)(240^2)}{12(32.2)(144)} = 3047 \text{ slug}\cdot ft^2$$



$$I_{yy} = \frac{2(1472)(183.6)^2}{12(32.2)(144)} = 1783 \text{ slug}\cdot ft^2$$

$$I_{zz} = \frac{2(1472)(240^2+183.6^2)}{12(144)(32.2)} = 4830. \text{ slug}\cdot ft^2$$

- **ENGINES** m: 2500 lbs./2 = 1250 lbs each

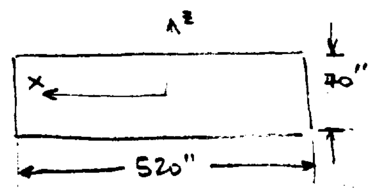


$$I_{zz} = I_{yy} = \frac{(1250)[3(28)^2 + 73^2]}{12(32.2)(144)}$$

$$I_{zz} = I_{xx} = 172.6 \text{ slug}\cdot ft^2$$

$$I_{xx} = \frac{(1250)(28^2)}{2(32.2)(144)} = 105.7 \text{ slug}\cdot ft^2$$

- **FUSELAGE**: m = 2546 lbs

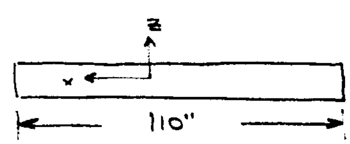


$$I_{zz} = I_{yy} = \frac{(2546)[3(70)^2 + 520^2]}{12(32.2)(144)}$$

$$I_{zz} = I_{yy} = 13{,}045 \text{ slug}\cdot ft^2$$

$$I_{xx} = \frac{(2,546)[\cancel{3}70^2]}{2(32.2)(144)} = 1{,}345 \text{ slug}\cdot ft^2$$

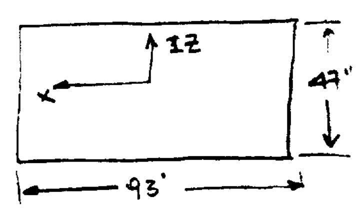
- **1 GUN**: m = 1200 lbs



$$I_{zz} = I_{yy} = \frac{1}{12}(1200)(110^2)$$

$$I_{zz} = I_{yy} = 121 \text{ slug}\cdot ft^2$$

- **AMMO CASE**: (w AMMO) m = 936 lbs



$$I_x = \frac{(936)[3(47^2) + 93^2]}{12(32.2)(144)} = 257.2 \text{ slug}\cdot ft^2$$

$$I_{yy} = I_{zz} = \frac{(936)(47)^2}{2(322)(144)} = 222.9 \text{ slug}\cdot ft^2$$

- WINGS: (see "GOOD" calculation)

  - Section ① & ⑤: $m = 917\ lb/2 = 458.5\ lbs$

    $I_{xx} = 287.4\ slug \cdot ft^2$

    $I_{yy} = 33.3\ slug \cdot ft^2$

    $I_{zz} = 320.8\ slug \cdot ft^2$

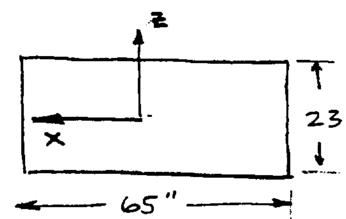
  - Sections ② & ④: $m = 1{,}419/2 = 709.5\ lbs.$

    $I_{xx} = 183.8\ slug \cdot ft^2$

    $I_{yy} = 275.8\ slug \cdot ft^2$

    $I_{zz} = 459.6\ slug \cdot ft^2$

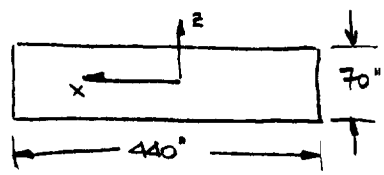
- ENGINES $m = 1200\ lbs/2 = 600\ lb$ each



$$I_{xx} = \frac{(600)(23^2)}{2(32.2)(144)} = 34.2\ slug \cdot ft^2$$

$$I_{zz} = I_{yy} = \frac{(600)[3(23)^2 + 65^2]}{12(32.2)(144)} = 62.7\ slug \cdot ft^2$$

- FUSELAGE: $m = 1407\ lbs$



$$I_{zz} = I_{yy} = \frac{(1407)[3(70)^2 + 440^2]}{12(32.2)(144)}$$

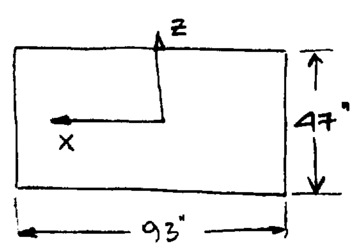
$$= 5{,}267\ slug \cdot ft^2$$

$$I_{xx} = 743.4\ slug \cdot ft^2$$

- GUN: (see "GOOD" airplane calculation)

$$I_{zz} = I_{yy} = 121\ slug \cdot ft^2$$

- AMMO CASE: (w/ ammo) $m = 234\ \#$



$$I_{xx} = \frac{(234)[3(47)^2 + 93^2]}{12(144)(32.2)}$$

$$I_{xx} = 64.2\ slug \cdot ft^2$$

$$I_{yy} = I_{zz} = \frac{(234)(47)^2}{2(32.2)(144)} = 55.7\ slug \cdot ft^2$$

• **WINGS**: (see "GOOD" calculations)

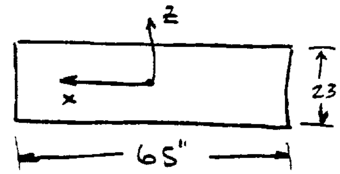
• SECTION ① & ⑤ $m = 917 \text{ lbs}/2 = 458.5\#$

$I_{xx} = 287.4 \text{ slug}\cdot ft^2$

$I_{yy} = 33.3 \text{ slug}\cdot ft^2$

$I_{zz} = 320.8 \text{ slug}\cdot ft^2$

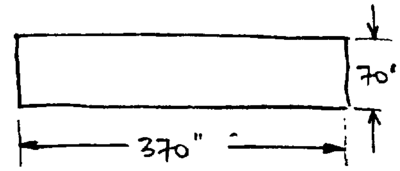
• **ENGINE**: $m = 500\#$



$$I_{xx} = \frac{(500)(23^2)}{2(32.2)(144)} = 28.5 \text{ slug}\cdot ft^2$$

$$I_{yy} = I_{zz} = \frac{(500)[3(23)^2 + 65^2]}{12(32.2)(144)} = 52.2 \text{ slug}\cdot ft^2$$

• **FUSELAGE**: $m = 801\#$



$$I_{zz} = I_{yy} = \frac{(801)[3(70)^2 + 370^2]}{12(32.2)(144)}$$

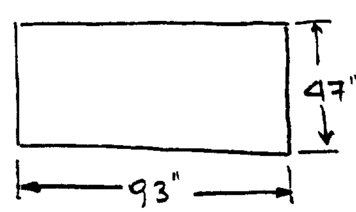
$$= 2{,}182 \text{ slug}\cdot ft^2$$

$$I_{xx} = \frac{801(70)^2}{2(32.2)(144)} = 423.2 \text{ slug}\cdot ft^2$$

• **GUN**: (see "Good" airplane calculation

$I_{zz} = I_{yy} = 121 \text{ slug}\cdot ft^2$

• **AMMO CASE**: (w/ ammo) $m = 608 \text{ lbs}$



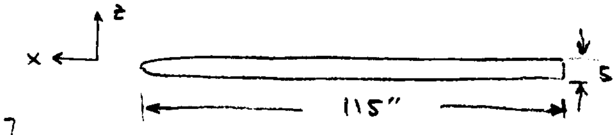
$$I_{xx} = \frac{(608)[3(47)^2 + 93^2]}{12(144)(32.2)}$$

$$= 166.9 \text{ slug}\cdot ft^2$$

$$I_{yy} = I_{zz} = \frac{608(47)^2}{2(144)(32.2)} = 144.8 \text{ slug}\cdot ft^2$$

• GOOD AIRPLANE :

a) SIDEWINDERS :

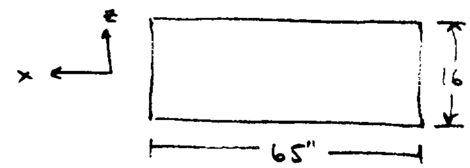


$$I_{zz} = I_{yy} = \frac{(328)\left[3(5)^2 + 115^2\right]}{12(32.2)(144)}$$

$$I_{zz} = I_{yy} = 78.4 \text{ slug}\cdot\text{ft}^2$$

$$I_{xx} = \frac{(328)(25)}{55{,}641} = 0.147 \text{ slug}\cdot\text{ft}^2$$

b) 19 round FFAR unguided rocket launcher:

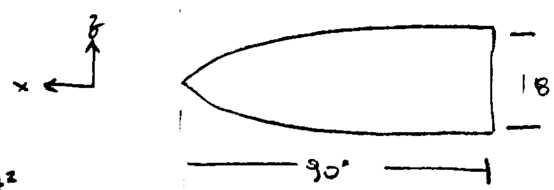


$$I_{zz} = I_{yy} = \frac{(830)\left[3(16)^2 + 65^2\right]}{55{,}641}$$

$$I_{zz} = I_{yy} = 74.5 \text{ slug}\cdot\text{ft}^2$$

$$I_{xx} = \frac{(830)(16^2)}{55{,}641} = 3.82 \text{ slug}\cdot\text{ft}^2$$

c) SUU-30B/B Cluster Bomb.

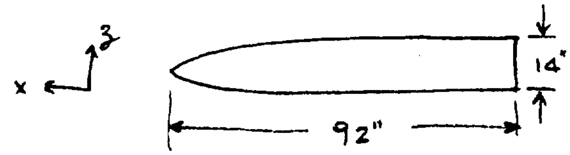


$$I_{zz} = I_{yy} = \frac{(3186)\left[3(18)^2 + 90^2\right]}{55{,}641}$$

$$I_{zz} = I_{yy} = 519. \text{ slug}\cdot\text{ft}^2$$

$$I_{xx} = \frac{3186(18)^2}{55{,}641} = 18.6 \text{ slug}\cdot\text{ft}^2.$$

d) MK. 20 bombs:



$$I_{yy} = I_{zz} = \frac{(3042)\left(3(14)^2 + 92^2\right]}{55{,}641}$$

$$I_{zz} = I_{yy} = 494 \text{ slug}\cdot\text{ft}^2$$

$$I_{xx} = \frac{(3042)(14^2)}{55{,}641} = 10.7 \text{ slug}\cdot\text{ft}^2$$

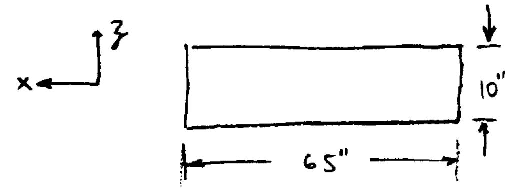
BAD AIRPLANE:

a) Sidewinders: $I_{zz} = I_{yy} = 78.4 \text{ slug}\cdot\text{ft}^2$

$I_{xx} = 0.147 \text{ slug}\cdot\text{ft}^2$

b) 7-round FFAR rocket launcher:

$$I_{zz} = I_{yy} = \frac{436\left[3(10)^2 + 65^2\right]}{55{,}641}$$



$$I_{yy} = I_{zz} = 35.5 \text{ slug}\cdot\text{ft}^2$$

$$I_{xx} = \frac{436(100)}{55{,}641} = 0.784 \text{ slug}\cdot\text{ft}^2$$

c) MK-20 bomb: $I_{zz} = I_{yy} = 494 \text{ slug}\cdot\text{ft}^2$

$I_{xx} = 10.7 \text{ slug}\cdot\text{ft}^2$

UGLY AIRPLANE: $I_{zz} = I_{yy} = 173 \text{ slug}\cdot\text{ft}^2$

$I_{xx} = 6.16 \text{ slug}\cdot\text{ft}^2$

AE 622 MOMENT OF INERTIA CALCULATIONS UPDATED 5-Apr-89
GOOD AIRPLANE

COMPONENT	Weight (lbs)	X (in)	Y (in)	Z (in)	WX (lb in)	WZ (lb in)	WX^2 (slug ft^2)	WY^2 (slug ft^2)	WZ^2 (slug ft^2)	ΔIxx (slug ft^2)	ΔIyy (slug ft^2)	ΔIzz (slug ft^2)	ΔIxz (slug ft^2)	COMPONENT
Wing														Wing
Section 1	432	436	-336	86	168,352	37,152	17,727	10,528	690	288	67	642	3,493	Section 1
Section 2	707	418	-174	86	295,526	60,802	26,666	4,621	1,129	184	276	460	5,481	Section 2
Section 3	3,136	406	0	86	1,273,216	269,696	111,587	0	5,007	3,047	1,783	4,830	23,615	Section 3
Section 4	707	418	174	86	295,526	60,902	26,666	4,621	1,129	184	276	460	5,481	Section 4
Section 5	432	436	336	86	188,352	37,152	17,727	10,528	690	288	67	642	3,493	Section 5
Horizontal Tail	416	782	0	210	325,312	87,360	54,915	0	3,960	0	0	0	14,733	Horizontal Tail
Vertical Tail	286	767	0	155	219,362	44,330	36,320	0	1,483	0	0	0	7,333	Vertical Tail
Boom	244	500	0	86	122,000	20,984	13,168	0	390	0	0	0	2,263	Boom
Fuselage	2,546	278	0	95	707,788	241,870	42,475	0	4,960	1,345	13,045	13,045	14,501	Fuselage
Nacelle	200	460	0	95	92,000	19,000	9,135	0	390	0	0	0	1,885	Nacelle
Landing Gear - Nose	235	159	3	40	101,050	9,400	1,282	0	81	0	0	0	322	Landing Gear - Nose
- Main	939	430	0	40	403,770	37,560	37,479	0	324	0	0	0	3,483	- Main
STRUCTURE TOTAL	10,280	410	0	90	4,212,254	926,108	395,149	30,298	20,232	5,335	15,513	20,077	86,085	STRUCTURE TOTAL
Left Engine	1,250	467	-24	100	583,750	125,000	58,848	155	2,698	106	173	173	12,590	Left Engine
Right Engine	1,250	467	24	100	583,750	125,000	58,848	155	2,698	106	173	173	12,590	Right Engine
Gearbox	1,500	537	0	115	805,500	172,500	93,374	0	4,282	0	0	0	19,978	Gearbox
Air Induction	700	412	0	115	288,400	80,500	25,650	0	1,998	0	0	0	7,153	Air Induction
Propeller	600	582	0	115	349,200	69,000	43,872	0	1,713	0	0	0	8,661	Propeller
Fuel System	564	429	0	86	241,956	48,504	22,407	0	900	0	0	0	4,488	Fuel System
Fuel Dump	26	469	0	86	12,194	2,236	1,235	0	42	0	0	0	226	Fuel Dump
Engine Starting System	46	457	0	100	21,022	4,600	2,074	0	99	0	0	0	453	Engine Starting System
Engine Controls	92	457	0	100	42,044	9,200	4,148	0	199	0	0	0	907	Engine Controls
Propeller Controls	287	582	0	115	167,034	33,005	20,985	0	819	0	0	0	4,143	Propeller Controls
Oil System	175	467	0	100	81,725	17,500	8,239	0	378	0	0	0	1,763	Oil System
POWERPLANT TOTAL	6,490	489	0	106	3,176,575	687,045	339,678	311	15,827	211	345	345	72,949	POWERPLANT TOTAL
Flight Controls	816	419	0	95	341,904	77,520	30,925	0	1,590	0	0	0	7,005	Flight Controls
Hydraulic and Pneumatic	324	380	0	90	123,120	29,160	10,099	0	567	0	0	0	2,390	Hydraulic and Pneumatic
Instrumentation	461	114	0	100	52,554	46,100	1,293	0	995	0	0	0	1,133	Instrumentation
Electrical System	505	380	0	100	191,900	50,500	15,741	0	1,090	0	0	0	4,139	Electrical System
A/C, Pressurization	161	380	0	95	61,180	15,295	5,019	0	314	0	0	0	1,253	A/C, Pressurization
Oxygen System	0	200	0	95	0	0	0	0	0	0	0	0	0	Oxygen System
Furnishings	165	160	0	105	26,400	17,325	912	0	393	0	0	0	598	Furnishings
Auxiliary Gear	203	360	0	100	73,080	20,300	5,679	0	438	0	0	0	1,576	Auxiliary Gear
Paint	121	360	0	100	43,560	12,100	3,385	0	261	0	0	0	939	Paint
30 mm Gatling Gun	1,200	195	0	73	234,000	87,600	9,850	0	1,380	0	121	121	3,684	30 mm Gatling Gun
FIXED EQUIPMENT	3,956	290	0	90	1,147,698	355,900	82,904	0	7,028	0	121	121	22,718	FIXED EQUIPMENT
EMPTY WEIGHT TOTALS	20,726	412	0	95	8,536,527	1,969,053	817,730	30,609	43,087	5,546	15,979	20,544	181,752	EMPTY WEIGHT TOTALS
Trapped Fuel and Oil	198	421	0	86	83,358	17,028	7,576	0	316	0	0	0	1,546	Trapped Fuel and Oil
Crew	225	146	0	115	32,850	25,875	1,035	0	642	0	0	0	815	Crew
OPERATING EMPTY TOTAL	21,149	409	0	95	8,652,735	2,011,956	826,341	30,609	44,045	5,546	15,979	20,544	184,112	OPERATING EMPTY TOTAL
Fuel	10,200	414	0	86	4,222,800	877,200	377,387	0	16,285	******	******	******	78,321	Fuel
Ammunition	936	216	0	105	202,176	98,280	9,427	0	2,228	257	223	223	4,578	Ammunition
Stores #1	3,186	358	0	45	1,140,588	143,370	88,145	0	1,393	19	519	519	11,069	Stores #1
Stores #2	3,042	374	0	45	1,137,708	136,890	91,852	0	1,330	11	494	494	11,041	Stores #2
Stores #3	830	390	0	45	323,700	37,350	27,252	0	363	4	75	75	3,141	Stores #3
Stores #4	382	436	0	45	166,552	17,190	15,676	0	167	0	78	78	1,616	Stores #4
TAKE-OFF WEIGHT	39,725	399	0	84	15,846,259	3,322,236	1,436,080	30,609	65,810	5,836	17,368	21,932	293,881	TAKE-OFF WEIGHT

	Σ WX^2	Σ WY^2	Σ WZ^2	Ixx	Iyy	Izz	Ixz
OPER WEIGHT EMPTY	62,148	30,609	2,72	38,883	80,854	113,300	6,420
TAKE-OFF WEIGHT	71,572	30,609	5,83	42,279	94,773	102,181	7,806

Moment of Inertia dimensions (slug ft^2)

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AE 622 MOMENT OF INERTIA CALCULATIONS
BAE AIRPLANE

UPDATED 5-Apr-89

COMPONENT	Weight (lbs)	X (in)	Y (in)	Z (in)	WX (lb in)	WZ (lb in)	WX^2 (slug ft^2)	WY^2 (slug ft^2)	WZ^2 (slug ft^2)	ΔIxx (slug ft^2)	ΔIyy (slug ft^2)	ΔIzz (slug ft^2)	ΔIxz (slug ft^2)
Wing													
Section 1	432	436	-336	86	188,352	37,152	17,727	10,528	690	288	33	321	3,493
Section 2	707	418	-174	86	295,526	60,802	26,666	4,621	1,129	184	276	460	5,481
Section 4	707	418	174	86	295,526	60,802	26,666	4,621	1,129	184	276	460	5,481
Section 5	432	436	336	86	188,352	37,152	17,727	10,528	690	288	33	321	3,493
Horizontal Tail	416	782	0	210	325,312	87,360	54,915	0	3,960	0	0	0	14,733
Vertical Tail	286	767	0	155	219,362	44,330	36,320	0	1,483	0	0	0	7,333
Boom	244	500	0	86	122,000	20,984	13,168	0	390	0	0	0	2,263
Fuselage	1,564	278	0	95	434,792	148,580	26,092	0	3,047	743	5,267	5,267	8,908
Nacelle	200	305	0	95	61,000	19,000	4,016	0	390	0	0	0	1,250
Landing Gear - Nose	200	209	3	40	41,800	8,000	1,886	0	69	0	0	0	361
- Main	500	430	0	40	215,000	20,000	19,957	0	173	0	0	0	1,855
STRUCTURE TOTAL	5,683	420	0	96	2,387,022	544,162	245,141	30,298	13,148	1,686	5,385	6,828	54,651
Left Engine	600	462	-24	100	277,200	60,000	27,645	75	1,295	34	63	63	5,978
Right Engine	600	462	24	100	277,200	60,000	27,645	75	1,295	34	63	63	5,978
Gearbox	600	522	0	115	313,200	69,000	35,292	0	1,713	0	0	0	7,768
Air Induction	896	435	0	115	389,760	103,040	36,599	0	2,558	0	0	0	9,667
Propeller	430	552	0	115	237,360	49,450	28,283	0	1,228	0	0	0	5,887
Fuel System	361	401	0	86	144,761	31,046	12,531	0	576	0	0	0	2,685
Fuel Dump	20	411	0	86	8,220	1,720	729	0	32	0	0	0	152
Engine Starting System	16	442	0	100	7,072	1,600	675	0	35	0	0	0	153
Engine Controls	82	442	0	100	36,244	8,200	3,458	0	177	0	0	0	782
Propeller Controls	45	550	0	115	24,750	5,175	2,938	0	128	0	0	0	614
Oil System	84	462	0	100	38,808	8,400	3,870	0	181	0	0	0	837
POWERPLANT TOTAL	3,734	470	0	106	1,754,575	397,631	179,668	149	9,218	68	125	125	40,500
Flight Controls	551	390	0	95	214,890	52,345	13,091	0	1,073	0	0	0	4,403
Hydraulic and Pneumatic	173	380	0	90	65,740	15,570	5,393	0	302	0	0	0	1,276
Instrumentation	289	164	0	100	47,396	28,900	1,678	0	624	0	0	0	1,022
Electrical System	376	380	0	100	142,880	37,600	11,720	0	812	0	0	0	3,081
A/C, Pressurization	130	380	0	95	49,400	12,350	4,052	0	253	0	0	0	1,012
Oxygen System	0	225	0	95	0	0	0	0	0	0	0	0	0
Furnishings	130	225	0	105	29,250	13,650	1,421	0	309	0	0	0	662
Auxiliary Gear	121	380	0	100	45,980	12,100	3,772	0	261	0	0	0	992
Paint	65	380	0	100	24,700	6,500	2,026	0	140	0	0	0	533
30 mm Gatling Gun	1,200	245	0	73	294,000	87,600	15,549	0	1,380	0	121	121	4,629
FIXED EQUIPMENT	3,035	301	0	88	914,236	266,615	63,702	0	5,156	0	121	121	17,610
EMPTY WEIGHT TOTALS	12,457	406	0	97	5,055,833	1,208,408	488,510	30,447	27,523	1,754	6,132	7,074	112,762
Trapped Fuel and Oil	109	390	0	86	42,510	9,374	3,579	0	174	0	0	0	788
Crew	225	196	0	115	44,100	25,875	1,866	0	642	0	0	0	1,094
OPERATING EMPTY TOTAL	12,791	402	0	97	5,142,443	1,243,657	493,955	30,447	28,339	1,754	6,132	7,074	114,644
Fuel	5,030	395	0	86	1,986,850	432,580	169,414	0	8,031	******	******	******	36,851
Ammunition	608	266	0	105	161,728	63,840	9,287	0	1,447	64	56	56	3,662
Stores #1	3,042	338	0	45	1,028,196	136,890	75,020	0	1,330	11	494	494	9,979
Stores #2	436	364	0	45	158,704	19,620	12,470	0	191	1	36	36	1,540
Stores #3	382	406	0	45	155,092	17,190	13,593	0	167	0	78	78	1,505
TAKE-OFF WEIGHT	22,289	387	0	86	8,633,013	1,913,777	773,739	30,447	39,504	1,830	6,795	7,738	168,181

	Ixx	Iyy	Izz	Ixz
OPER WEIGHT EMPTY	34,438	56,030	85,182	6,711
TAKE-OFF WEIGHT	36,310	62,760	82,379	8,170

Inertia dimensions (slug ft^2)

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AE 622 MOMENT OF INERTIA CALCULATIC UPDATE 5-Apr-89
UGLY AIRPLANE

COMPONENT	Weight (lbs)	X (in)	Y (in)	Z (in)	WX (lb in)	WZ (lb in)	WX^2 (slug ft^2)	WY^2 (slug ft^2)	WZ^2 (slug ft^2)	ΔIxx (slug ft^2)	ΔIyy (slug ft^2)	ΔIzz (slug ft^2)	ΔIxz (slug ft^2)	COMPONENT
Wing														Wing
Section 1	432	381	-336	86	164,592	37,152	13,537	10,528	690	287	33	321	3,053	Section 1
Section 5	432	381	336	86	164,592	37,152	13,537	10,528	690	287	33	321	3,053	Section 5
Horizontal Tail	286	639	0	210	182,754	60,060	25,209	0	2,723	0	0	0	8,277	Horizontal Tail
Vertical Tail	286	620	0	155	177,320	44,330	23,732	0	1,483	0	0	0	5,927	Vertical Tail
Boom	166	480	0	86	79,680	14,276	8,256	0	265	0	0	0	1,478	Boom
Fuselage	1,143	277	0	95	316,611	108,585	18,932	0	2,227	432	2,182	2,182	6,487	Fuselage
Nacelle	75	408	0	107	30,600	8,025	2,695	0	185	0	0	0	706	Nacelle
Landing Gear - Nose	80	224	3	40	17,920	3,200	867	0	28	0	0	0	155	Landing Gear -
- Main	320	415	0	40	132,800	12,800	11,897	0	111	0	0	0	1,146	-
STRUCTURE TOTAL	3,220	393	0	101	1,266,869	325,580	118,661	21,056	8,401	1,007	2,249	2,824	30,281	STRUCTURE TO
Engine	500	430	-24	107	215,000	53,500	19,957	62	1,236	29	52	52	4,961	Engine
Gearbox	300	482	0	112	144,600	33,600	15,045	0	812	0	0	0	3,493	Gearbox
Air Induction	252	408	0	112	102,816	28,224	9,055	0	682	0	0	0	2,483	Air Induction
Propeller	300	501	0	112	150,300	33,600	16,255	0	812	0	0	0	3,630	Propeller
Fuel System	137	376	0	86	51,512	11,782	4,181	0	219	0	0	0	955	Fuel System
Fuel Dump	11	401	0	86	4,411	946	382	0	18	0	0	0	82	Fuel Dump
Engine Starting System	4	420	0	107	1,680	428	152	0	10	0	0	0	39	Engine Startinc
Engine Controls	48	420	0	107	20,160	5,136	1,828	0	119	0	0	0	465	Engine Controls
Propeller Controls	28	501	0	112	14,028	3,136	1,517	0	76	0	0	0	339	Propeller Cont
Oil System	35	430	0	100	15,050	3,500	1,397	0	76	0	0	0	325	Oil System
POWERPLANT TOTAL	1,615	446	0	108	719,557	173,852	69,770	62	4,059	29	52	52	16,773	POWERPLANT
Flight Controls	357	386	0	95	137,802	33,915	11,482	0	696	0	0	0	2,823	Flight Controls
Hydraulic and Pneumatic	86	385	0	90	33,110	7,740	2,752	0	150	0	0	0	643	Hydraulic and I
Instrumentation	178	179	0	100	31,862	17,800	1,231	0	334	0	0	0	687	Instrumentatio
Electrical System	254	385	0	100	97,790	25,400	8,127	0	548	0	0	0	2,109	Electrical Syst
A/C, Pressurization	111	385	0	95	42,735	10,545	3,552	0	216	0	0	0	876	A/C, Pressuriz
Oxygen System	0	272	0	95	0	0	0	0	0	0	0	0	0	Oxygen System
Furnishings	116	230	0	105	26,680	12,180	1,325	0	276	0	0	0	604	Furnishings
Auxiliary Gear	68	385	0	100	26,180	6,800	2,176	0	147	0	0	0	565	Auxiliary Gear
Paint	32	390	0	100	12,480	3,200	1,051	0	69	0	0	0	269	Paint
30 mm Gatling Gun	1,200	260	0	73	312,000	87,600	17,511	0	1,330	0	121	121	4,912	30 mm Gatling
FIXED EQUIPMENT	2,402	300	0	85	720,639	205,180	49,206	0	3,867	0	121	121	13,488	FIXED EQUIPMI
EMPTY WEIGHT TOTALS	7,237	374	0	97	2,707,065	704,612	237,637	21,118	16,327	1,036	2,422	2,997	60,541	EMPTY WEIGHT
Trapped Fuel and Oil	55	382	0	86	21,010	4,730	1,733	0	88	0	0	0	390	Trapped Fuel a
Crew	225	211	0	115	47,475	25,875	2,162	0	642	0	0	0	1,177	Crew
OPERATING EMPTY TOTAL	7,517	369	0	98	2,775,550	735,217	241,532	21,118	17,057	1,036	2,422	2,997	62,108	OPERATING EM
Fuel	1,750	376	0	86	658,000	150,500	53,407	0	2,794	******	******	******	12,204	Fuel
Ammunition	608	281	0	105	170,848	63,840	10,363	0	1,447	167	145	145	3,869	Ammunition
Stores #1	1,060	338	0	45	358,280	47,700	26,141	0	463	6	173	173	3,477	Stores #1
TAKE-OFF WEIGHT	10,935	362	0	91	3,962,678	997,257	331,444	21,118	21,761	1,209	2,740	3,315	81,658	TAKE-OFF WEI

	Σ WX^2	Σ WY^2	Σ WZ^2
OPER. WEIGHT EMPTY	20,304	21,118	1,534
TAKE-OFF WEIGHT	21,456	21,118	2,128

Ixx	Iyy	Izz	Ixz
23,688	24,260	44,419	3,507
24,455	26,324	42,574	3,646

Inertia dimensions: (slug ft^2)

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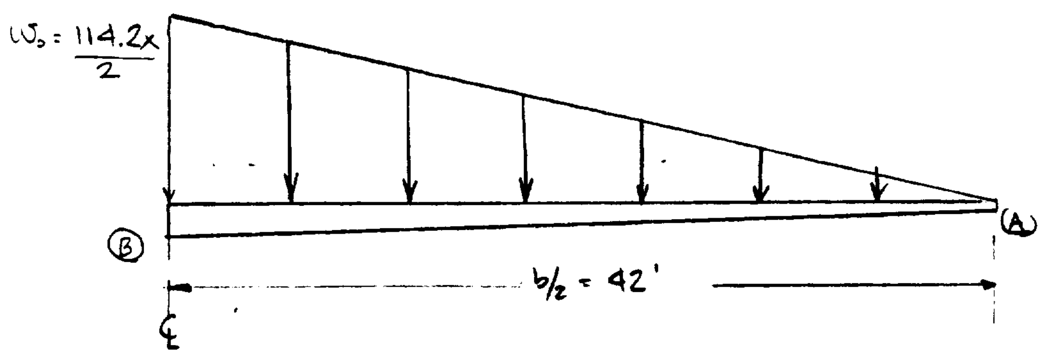
1. WING:

The bending moment relief due to the wing weight is calculated as follows. The weight distribution across the span is considered to be triangular. All calculations are for the Good wing since it is critical having to support all loads from the other two airplanes.

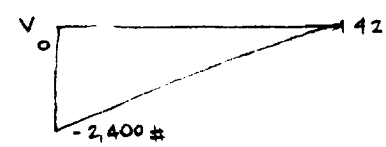


For $n = 7.33$; $W_o = 418.5$ #/ft

$W_{WING} = 4{,}800$ # (Rpt 1, p. 31)

Calculating the shear: (area under load curve ; $V = -\int w\,dx$)

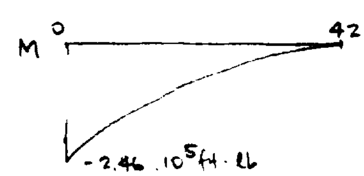
$$V_B - V_A = -\frac{1}{2} W_o \cdot x$$



at A, $V_A = 0$,

$$\therefore V_B = -\frac{1}{2}(418)(42) = -8789 \text{ lbs}$$

Calculating the moment:



$$M_B - \cancel{M_A}^{0} = -\frac{1}{3}(W_o)(x)$$

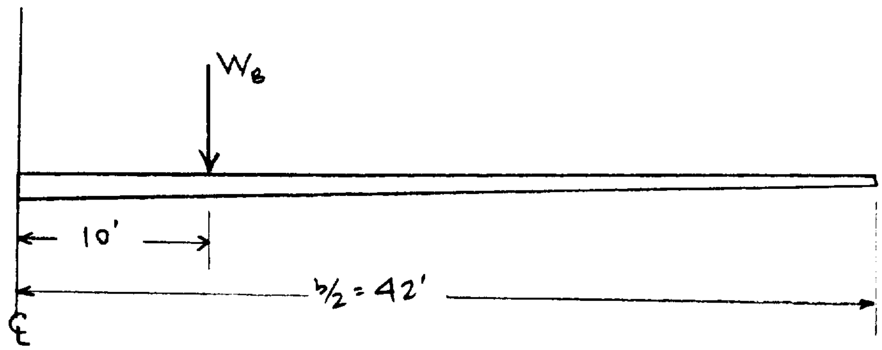
since $M_A = 0$

$$M_B = -\frac{1}{3}(419)(42)^2 = -2.46 \times 10^5 \text{ ft}\cdot\text{lbs.}$$

and the bending moment diagram is shown in fig. 1. It represents the inertial relief due to the wing weight. (for a load factor of 1.0)

2. Boom:

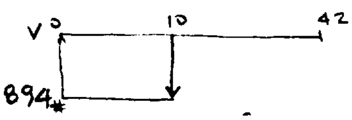
The weight of the boom is considered to act as a point load at 10' from the center-line. Again, the analysis is for the Good wing since it is the most critical:



$W_{BOOM} = \frac{244}{2}$ lbs (Rpt 1, p. 31) = 122 lb

· Calculating the shear:

$$V_B - \cancel{V_A}^{0} = (-122 \text{ lbs})7.33 = 894 \text{ lbs}$$

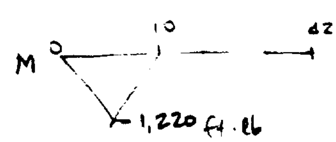


· $V_A = 0$

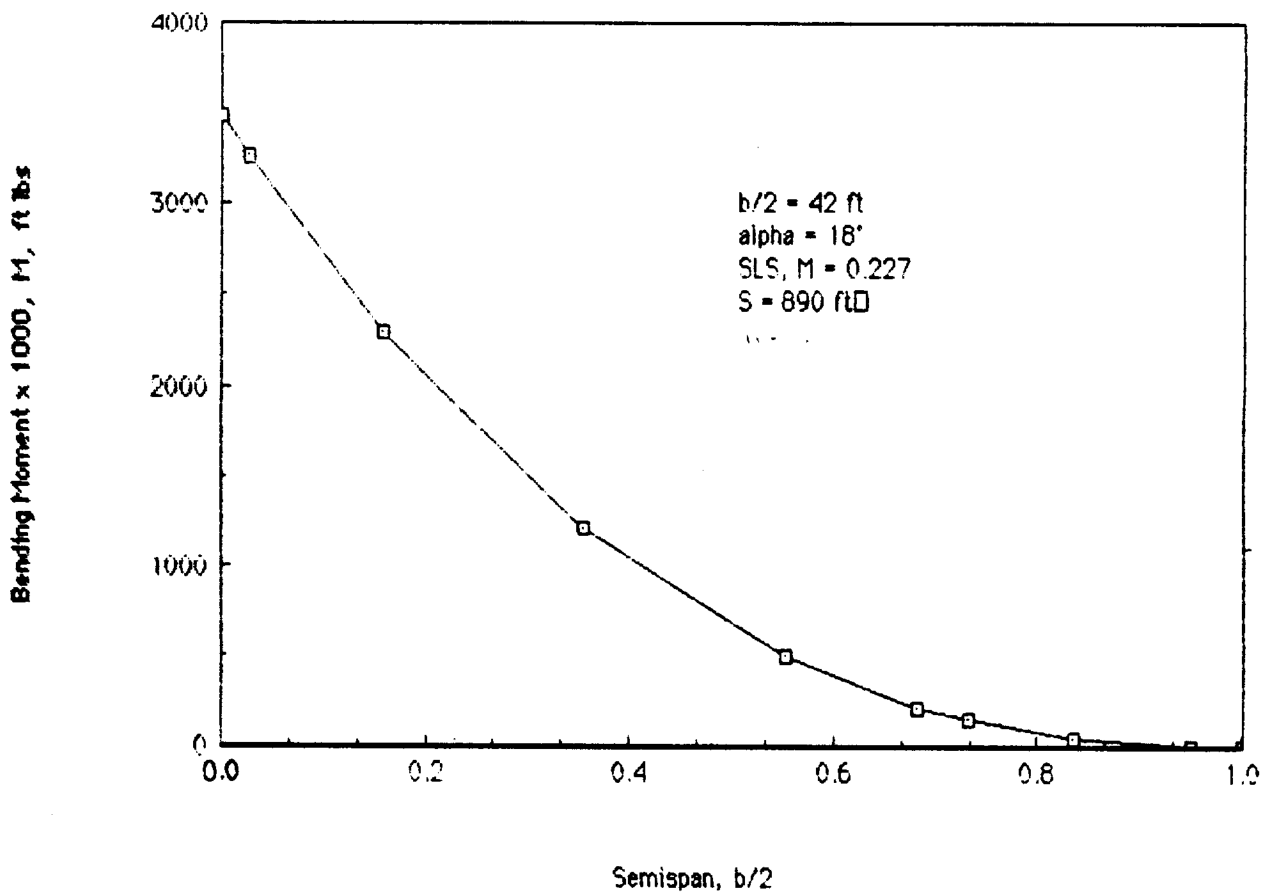
· Calculating the bending moment:

$$M - \cancel{M_A}^{0} = (-122\ x)\,n$$

$M_A = 0, \quad M_{max} = 244(10)(7.33) = 1.79 \times 10^4$ ft·lb



the bending-moment diagram is shown in fig. 1. It represents the inertial relief due to the weight of the boom. Compared to the inertial relief due to the wing weight, it is almost negligible. Thus, for simplicity, it is not considered to be significant & not accounted for.



Bending Moment A12

From fig. 3, the following area ratios were obtained:

$$S_1 = 74$$

$$S_2 = 57$$

$$S_3 = 26$$

So, for the weights of the wings:

$$W_{UGLY} = 864 \text{ lb} \quad (\text{Report } 1, \text{ p. } 33)$$

so:

$$W_{BAD} = 864\left(\frac{S_2 + S_3}{S_3}\right) = \underline{2{,}758 \text{ lbs}}$$

$$W_{GOOD} = 864\left(\frac{S_1 + S_2 + S_3}{S_3}\right) = \underline{5{,}217 \text{ lbs.}}$$

And, the following wing weights were obtained from the weight & balance section of report 1. They correspond to weights obtained from the equations of Part V, Roskam.

$$W_U = 864 \text{ lbs}, \quad (\text{Rpt } 1, \text{ p. } 33)$$

$$W_{BAD} = 2225 \text{ lbs}, \quad (\text{Rpt } 1, \text{ p. } 32)$$

$$W_{GOOD} = 4800 \text{ lbs}, \quad (\text{Rpt } 1, \text{ p. } 31)$$

• Thus, the following penalties (weight) are associated with the three aircraft:

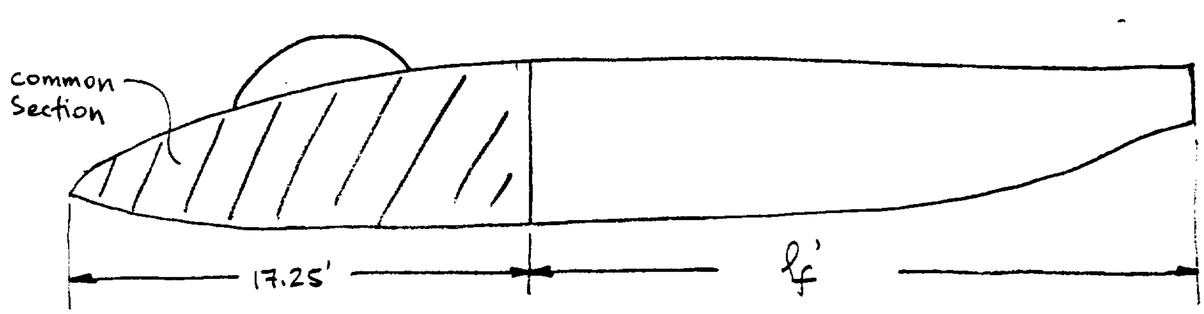
$$\boxed{\begin{aligned} W_{UGLY} &= 0 \\ W_{BAD} &= 533 \text{ lbs} \\ W_{GOOD} &= 417 \text{ lbs} \end{aligned}}$$

– To estimate the weight penalty due to the common nose section for the three airplanes, the following method was used:

1.- The weights for the fuselages without the nose sections was determined from Pt.5, Roskam equations.

2. These weights were subtracted from the actual fuselage weights obtained from Weight and Balance, Report 1, giving the nose cone weights.

3. Since the nose cone for the 'Good' is common to all three, this weight was added to the weights of the fuselages without nose cones. This gives the new fuselage weight.



1, 2) Fuselage weight (w/o nose section) calculation: (All eq'ns from Roskam, Pt. 5)

* GOOD: $l_f' = 24.8$ ft

- GD METHOD:

$$W_f' = 10.43\,(1.25)^{1.42}\,(7.50)^{0.283}\,(40.45)^{0.98}\left(\frac{24.8}{5.5}\right)^{0.71}$$

$$W_f' = 2{,}770 \text{ lb} \quad \text{vs} \quad 3{,}606 \text{ lb} \quad (\text{p. }31,\ \text{Rpt } 1)$$

$\Rightarrow$ Nose cone wt: 836 lb

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- USAF Method:

$$W_f' = 200\left[(3.64)^{0.286}(2.48)^{0.857}(1.05)(4)^{0.338}\right]^{1.1}$$

$$W_f' = 1266 \text{ lb} \quad \text{vs} \quad 2052 \text{ lb} \quad (p.\ 31,\ Rpt\ 1)$$

⇒ Nose cone wt: 786 lb

→ Average Nose cone wt: 811 lbs

and, for 10% wt. savings due to advanced materials: = $\boxed{730 \text{ lbs}}$

*** BAD:** $\ell_f' = 19.8$ ft

- GD Method:

$$W_f' = 10.43(1.25)^{1.42}(6)^{0.283}(21.6)^{0.95}(19.8/5.5)^{0.71}$$

$$W_f' = 1100 \text{ lb} \quad \text{vs.} \quad 1704 \text{ lbs} \quad (p.\ 32,\ Rpt\ 1)$$

⇒ Nose Cone wt: 604 lb

- USAF Method:

$$W_f' = 200\left[(1.94)^{0.286}(1.98)^{0.857}(1.05)(3.5)^{0.338}\right]^{1.1}$$

$$W_f' = 753 \text{ lb} \quad \text{vs.} \quad 1422 \quad (p.\ 32,\ Rpt\ 1)$$

⇒ Nose Cone wt: 669 lb

→ Average Nose cone wt: 637 lbs

→ , for 10% wt. savings due to advanced materials: = $\boxed{573 \text{ lbs}}$

*** UGLY:** $\ell_f' = 10.75$ ft

- GD Method:

$$W_f' = 10.43(1.25)^{1.42}(6.0)^{0.283}(10.8)^{0.95}(1.95)^{0.71}$$

$$W_f' = 367 \text{ lbs} \quad \text{vs.} \quad 711 \text{ lbs} \quad (Rpt\ 1,\ p.\ 33)$$

⇒ Nose Cone wt: 345 lbs.

- USAF Method:

$$W_f' = 200\left[(0.97)^{0.286}(1.075)^{0.857}(1.05)(3.50)^{0.338}\right]^{1.1}$$

$W_f' = 356$ lb vs. 874 lbs (Rpt. 1, p. 33)

⇒ Nose Cone wt: 518 lbs.

→ Average Nose Cone wt: 432 lbs.

→ for a 10% wt savings due to advanced materials = $\boxed{388 \text{ lbs}}$

3) Since the Good nose section is common, the weight of all three sections is

$$\boxed{W_{N.S.} = 730 \text{ lbs}}$$

So, the following total fuselage sections are:

	GOOD	BAD	UGLY	
$W_{N.S.}$	730	730	730	(lbs) (Nose section)
W_f'	1,816	834	413	(lbs) (Fuselage w/o Nose)
total W_f	2,546	1,564	1,143	(lbs) (total)

Note: W_f' is obtained by subtracting the average nose cone weight from the total fuselage weight obtained from Weight & Balance, Rpt 1.

So, in summary:

	GOOD	BAD	UGLY	
• Initial W_f estimate	2,546	1,407	801	(lbs)
• Current W_f estimate	2,546	1,564	1,143	(lbs)
• Penalty	0	157	342	(lbs)

Note:

- The following data was obtained from Chapter 10, Report 1.

	GOOD	BAD	UGLY	
Main Gear Wt.	939	793	705	(lbs)
Nose Gear Wt.	235	235	235	(lbs)
Penalty: MG/NG	0/0	293/35	385/155	(lbs)

From pt V, Roskam, the following landing gear weights were computed,

	GOOD	BAD	UGLY	
M. G.	939	500	320	(lbs).
N. G	235	200	80	

From these figures, it appears that a revision of the commonality requirements is necessary. The penalty incurred by the Bad & especially the Ugly aircraft are excessive.

$$W_B = \cancel{\ } \; 0.021\, K_f \left(\frac{V_D \, l_n}{w_f + h_f} \right)^{1/2} \left(S_{fgs} \right)^{1.2}$$

$$W_B = 0.021\,(1.07) \left(\frac{400 \cdot 35}{2 + 2} \right)^{1/2} \left(40 \right)^{1.2} = 120 \text{ lbs.}$$

1) Fairchild
C-119B : Tailboom & nacelle:

Nacelle group / GW = 0.040

Nacelle wt = 2538

2) A W Argosy :

Tailbooms : 2,360 lbs

Tailboom/GW = 0.0288

→ Assume : $\frac{1}{2}(0.040 + 0.0288) = \underline{0.0344}$

- <u>GOOD</u>: 0.0344(39,725) = 1,366 lbs
- <u>BAD</u>: 0.0344 (22,289) = 766 lbs
- <u>UGLY</u>: 0.0344(10,935) = 376 lbs. + 15% = 432 lbs

<u>Note:</u> GOOD & Bad have common booms.

GOOD, BAD = 1,366 lbs.

APPENDIX B

The purpose of this appendix is to present the calculations done to verify the performance of the Good, Bad and Ugly aircraft. The table of contents listed below shows what is included in this appendix.

Table of Contents

Maneuvering:

a) Good: 5 g's sustained, 150 Kts, SL fully loaded.

1. Sustained:

$W = W_{TO} = 39{,}725$ lbs
$S = 890\ ft^2$
$T = 8{,}900$ shp.
$A = 8$
$e = 0.80$
$\bar{q} = 76.3$ psf
$C_{D_0} = 0.0252$ (with stores)

→ $C_{L_{max}} = 1.3$ — (trimmed; check w/ Wayne)

$\delta = 1.0$
$M = (150 \cdot 1.689)/1116.4 = 0.227$

Method from Pt VII, Chap. 5

$$n_{max} = \frac{1{,}482\, \delta M^2 C_{L_{max}} S}{W} = 1{,}482 \frac{(1.0)(0.227)^2(1.3)(890)}{39{,}725}$$

$$n_{max} = 2.22$$

$$P/W_{req} = \left[C_{D_0} + \frac{C_{L_{man}}^2}{\pi A e} \right] \frac{U_1}{550}$$

$$C_{L_{man}} = n \frac{W}{\bar{q} S} = 5.0 \left(\frac{39{,}725}{76.3 \cdot 890} \right)$$

$$C_{L_{man}} = 2.93$$

$$P/W_{req} = \left[0.0252 + \frac{2.93^2}{\pi(8)(0.8)} \right] \frac{253}{550} = 0.207$$

$$P_{req} = 8{,}236 \text{ shp}$$ ← (meets req'mt)

⇒ can pull ⇒ $n_{max} = 5.2$ g's.

b) Bad: 5 g's sustained, 125 Kts, SL, fully loaded.

1. sustained.

$W = W_{TO} = 22,289$ lbs
$S = 577\ ft^2$
$T = 3900$ shp $\cong$ 10,166 lbs
$A = 7.2$
$e = 0.80$
$\bar{q} = 76.0$ psf
$C_{D_0} = 0.0280$ w/ stores

Check $\longrightarrow$ $C_{L_{max}} = 1.3$ $\qquad C_{L_{man}} = 5\left(\frac{22,289}{76 \cdot 577}\right) = 2.54$

$$P/W_{req'd} = \left[0.028 + \frac{2.54^2}{\pi(7.2)(0.8)}\right]\frac{253}{550} = 0.292$$

$P_{req} = 3917$ hp (meets req'mt)

($n_{actual} = 4.99$)

c) Ugly: 5g's sustained, 125 Kts, S.L., fully loaded.

1. sustained:

$W = W_{TO} = 10,935$ lb
$S = 335\ ft^2$
$T = 2,000$ shp $\cong$ 5,213 lbs
$A = 5.9$
$e = 0.80$
$\bar{q} = 76.3$
$C_{D_0} = 0.0299$
$C_{L_{max}} = 1.3$ $\qquad C_{L_{man}} = 5.0\left(\frac{10,935}{76.3 \cdot 335}\right) = 2.14$

$$P/W_{req'd} = \left[0.0299 + \frac{2.14^2}{\pi(5.9)(0.8)}\right]\frac{253}{550}$$

$P_{req'd} = 1,702$ shp (meets req't)

$n_{actual} = 5.2$

2) Maximum Speed: (all obtained from performance diagrams)

Good: 350 Kts, S.L., fully loaded;

actual: 364 Kts met ✓

Bad: 250 Kts, S.L, fully loaded.

actual: 299 Kts met ✓

Ugly: 250 Kts, S.L, fully loaded

actual: 281 Kts met ✓

(Method assumed valid to within ± 50 hp - due to inaccuracy in THP av. curves. Therefore, power required to run the various systems was not included in the calculations.)

3) Stall Speed

Good:

$C_{L_{max}}$ (clean) = 1.3 ρ_{SL} = 0.002377 slug/ft³

$C_{L_{max}}$ (T-O) = 1.4 $\rho(5000)$ = 0.002048 sl/ft³

$C_{L_{max}}$ (Land) = 1.5 $\rho(15{,}000)$ = 0.00149 slug/ft³

Stall speed:

$$V_s = \sqrt{\frac{2W}{\rho C_L S}}$$

- clean: (C_L = 1.3) fully loaded
  - S.L.: 100 Kts
  - 5,000 ft: 108 Kts
  - 15,000 ft: 127 Kts
- t-off (C_L=1.4) — 96.9 Kts
- sea level Land (C_L=1.5) W_L = 90% W_{TO} — 88.9 Kts

Bad:

$C_{L_{max}}$ (clean) = 1.3

$C_{L_{max}}$ (T-O) = 1.4

$C_{L_{max}}$ (Land) = 1.8

W_{TO} = 22,289 lbs
S = 577 ft²

- clean (C_L = 1.3) fully loaded
  - S.L: 93.6 Kts
  - 5,000 ft: 100. Kts
  - 15,000 ft: 118 Kts
- T-O (C_L = 1.4) — 90.2 Kts

sea level

- Landing (C_L = 1.8) — 75.5 Kts

W_L = 90% W_{TO}

Ugly:

$C_{L_{max}}$ (clean) = 1.3

$C_{L_{max}}$ (T-O) = 1.6

$C_{L_{max}}$ (Land) = 2.2

W_{TO} = 10,935 lbs
S = 335 ft²

- clean (C_L = 1.3) fully loaded
  - S.L: 86.1 Kts
  - 5000 ft: 92.7 Kts
  - 15,000 ft: 108. Kts
- T-O (C_L = 1.6) — 77.6 Kts

sea level

- Landing (C_L = 2.2) — 62.8 Kts

W_L = 90% W_{TO}

3) Groundrun:

Good: 2,000 ft, steel planking

$$S_{TOG} = \left[\frac{V_{LOF}^2}{2g}\right] \Big/ \left[\bar{T}/W_{TO} - \mu'\right]$$

$$V_{LOF} = 1.1\ V_{s_{TO}} \quad \text{for military}$$

$$\mu' = \mu_g + 0.72\left(\frac{C_{D_0}}{C_{L_{max}}}\right)_{T\text{-}O}$$

$$\bar{T} = 5.75 \cdot P_{TO}\left[\frac{\sigma N D_p^2}{P_{TO}}\right]^{1/3}$$

So;:

$$V_{LOF} = 1.1\,(163.6) = 180\ \text{ft/s}$$

$$\mu' = 0.02 + 0.72\left(\frac{0.0252}{1.4}\right) = 0.033$$

$$\bar{T} = 5.75 \cdot 12{,}000\left[\frac{1}{1.79}\right]^{1/3} = 12{,}236\ \text{shp.}$$

so:

$$S_{TOG} = \left[\frac{180^2}{64.4}\right] \Big/ \left[\frac{12{,}236}{39{,}325} - 0.033\right]$$

$$\therefore\ S_{TOG} = 1808\ \text{ft}$$

(meets req'mt.)

Bad 1,200 ft, soft field.

(All parameters & equations defined above)

$$V_{LOF} = 1.1\,(152) = 167.6\ \text{ft/s}$$

$$\mu' = 0.10 + 0.72\left(\frac{0.0280}{1.4}\right) = 0.114$$

$$\bar{T} = 5.75 \cdot 6{,}210\left[\frac{1}{99.2}\right]^{1/3} = 9{,}858\ \text{shp}$$

$$S_{TOG} = \left[\frac{167.6^2}{64.4}\right] \Big/ \left[\frac{9{,}858}{22{,}289} - 0.114\right]$$

$$S_{TOG} = 1{,}328\ \text{ft}$$

9.7% discrepancy. Does not meet

Ugly: 1,000 ft, soft field

All parameters & equations are described above

- $V_{LOF} = 1.1(131) = 144.2$ ft/s
- $\mu' = 0.1 + 0.72\left(\frac{0.0299}{1.6}\right) = 0.114$
- $T = 5.75 \cdot 3{,}968 \left(\frac{1}{49.6}\right)^{1/3} = 6{,}210$ shp.

$$S_{TOG} = \left[\frac{144.2^2}{64.4}\right] \Big/ \left[\frac{6{,}210}{10{,}935} - 0.114\right]$$

$$S_{TOG} = 711 \text{ ft}$$ (meets requirement)

5) Landing.

- Good: $S_L = S_{air} + S_{LG}$

$$S_{air} = \frac{1}{\bar{\gamma}}\left[\frac{V_A^2 - V_{TD}^2}{2g} + h_L\right]$$

- $V_A = 1.2\, V_{s_L}$ (Air Force)
- $\bar{\gamma} = 0.10$
- $h_L = 50$ ft

$$V_{TD} = V_A \left[1 - \frac{\bar{\gamma}^2}{\Delta n}\right]^{1/2}, \quad \Delta n = 0.10$$

$$S_{LG} = \frac{V_{TD}^2}{2\bar{a}} \; ; \quad \bar{a} = 0.40 \cdot g = 12.9$$

$V_A = 1.2(150) = 180$ ft/s

$$V_{TD} = 180\left[1 - \frac{0.10^2}{\cancel{0.10}}\right]^{1/2} = 171 \text{ ft/s}$$

$$S_{LG} = \frac{171^2}{2(12.9)} = 1{,}132 \text{ ft}$$

$$S_{air} = \frac{1}{0.10}\left[\frac{180^2 - 171^2}{64.4} + 50\right] = 990 \text{ ft}$$

$$S_L = 990 + 1{,}132 = 2{,}123\ ft$$

<u>Bad</u>: All parametrs defined previously.

$$V_A = 1.2(127.5) = 153\ ft/s$$

$$V_{TD} = 153\left[1 - 0.10\right]^{1/2} = 145\ ft/s$$

$$S_{LG} = \frac{145^2}{2(12.9)} = 816\ ft$$

$$S_{air} = \frac{1}{0.10}\left[\frac{153^2 - 145^2}{64.4} + 50\right] = 870\ ft$$

$$S_L = 816 + 870 = 1{,}686\ ft$$

<u>Ugly</u>: All parameters defined previously.

$$V_A = 1.2(106) = 127\ ft/s$$

$$V_{TD} = 127\left[1 - 0.10\right]^2 = 120\ ft/s$$

$$S_{LG} = \frac{120^2}{2(12.9)} = 562\ ft$$

$$S_{air} = \frac{1}{0.10}\left[\frac{127^2 - 120^2}{64.4} + 50\right] = 768\ ft$$

$$S_L = 562 + 768 = 1{,}331\ ft$$

7) Endurance:

Good: — 1 hr at 5,000 ft

$$E = 778\left(\frac{\eta_p}{c_p}\right)\sqrt{\rho\, S}\left(\frac{C_L^{3/2}}{C_D}\right)\left(\frac{1}{\sqrt{W_{end}}} - \frac{1}{\sqrt{W_1}}\right)$$

$$E = 778\left(\frac{0.86}{0.40}\right)\sqrt{0.00204 \cdot 890}\left(\frac{0.611^{1.5}}{0.0437}\right)\left(\frac{1}{\sqrt{32{,}581}} - \frac{1}{\sqrt{34{,}010}}\right)$$

$W_i = (39{,}725)(0.856) = 34{,}010$ lb

$W_e = (39{,}725)(0.8202) = 32{,}581$ lbs

$$C_L = \frac{(33{,}295)}{61.2 \cdot 890} = 0.6113$$

$C_D = 0.0252 + 0.0496(0.6113)^2 = 0.0437$

$E = 2.89$ hrs (meets req't) ⟵

Bad: 4 hrs @ 5,000'

$W_i = 0.946(22{,}289) = 21{,}087$ lbs

$W_e = 0.827(21{,}087) = 17{,}439$ lbs.

$$C_L = \frac{(19{,}263)2}{131 \cdot 577} = 0.509$$

$C_D = 0.0280 + 0.0552(0.509)^2 = 0.0423$

$$E = 778\left(\frac{0.81}{0.46}\right)\sqrt{0.00204 \cdot 577}\left(\frac{0.509^{3/2}}{0.0423}\right)\left(\frac{1}{\sqrt{17{,}439}} - \frac{1}{\sqrt{21{,}087}}\right)$$

$E = 5.16$ hrs meets reqmt ⟵

Ugly: 2 hrs @ 5,000 ft

$W_i = (10{,}935)(0.954) = 10{,}430$ lbs

$W_e = (10{,}439)(0.929) = 9{,}689$ lbs

$$C_L = \frac{2(10{,}059)}{131 \cdot 337} = 0.456$$

$C_D = 0.0299 + 0.0673(0.456)^2 = 0.0439$

$$E = 778\left(\frac{0.79}{0.39}\right)\sqrt{0.00204\cdot 337}\left(\frac{0.456^{3/2}}{0.0439}\right)\left(\frac{1}{\sqrt{9689}} - \frac{1}{\sqrt{10,430}}\right)$$

$E = 3.37$ hrs meets req't

Climb

Good: meet MIL spec climb req'ts.

Requirements:

T-0 — $V_{TO} = 1.1 V_{STO}$; $CGR \geq 0.005$

$RC > 500$ fpm, OEI, S.L, fully loaded.

$$Rc = 33{,}000 \cdot RCP$$

$$RCP = \frac{\eta_p}{W/P} - \left[\frac{\sqrt{W/S}}{19 C_L^{3/2}/C_D\, \sigma^{1/2}}\right]$$

$$RCP = \frac{0.86}{6.62} - \left[\frac{\sqrt{44.6}}{19\ \frac{1.4^{3/2}}{0.122}}\right] = 0.022$$

0.13

$RC = 726$ fpm.

$$CGR = \frac{RC}{V} = \frac{726\text{ fpm}}{1.1(163)60} = 0.067$$

Bad: same requirements.

$$RCP = \frac{0.81}{8.91} - \left[\frac{\sqrt{38.6}}{19\cdot \frac{1.4^{3/2}}{0.125}}\right] = 0.0195$$

$RC = 33{,}000(0.0195) = 645$ fpm

$$CGR = \frac{RC}{V} = \frac{645}{1.1(152)60} = 0.064$$

Ugly: same requirements

$$RCP = \frac{0.79}{4.12} - \left[\frac{\sqrt{32.4}}{19 \cdot \frac{1.6^{3/2}}{0.202}}\right] = 0.023$$

$$RC = 33{,}000(0.023) = 759 \text{ fpm.}$$

$$CGR = \frac{759}{1.1(106)60} = 0.108$$

Combat Radius:

Good: $R = 326\left(\frac{\eta_p}{C_p}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_{in.}}{W_{end}}\right)$

- cruise: $R = 326\left(\frac{0.86}{0.39}\right)(6)\ln\left(\frac{1}{0.894}\right)$

$$R = 483 \text{ nm}$$

- s.L cruise: $R = 326\left(\frac{0.81}{0.39}\right)(6)\ln\left(\frac{1}{0.981}\right)$

$$R = 77.9 \text{ nm}$$

total combat Radius: 560 nm
required " " : 400 nm

Bad:

- cruise: $R = 326\left(\frac{0.81}{0.39}\right)(6)\ln\left(\frac{1}{0.978}\right)$

$$R = 90.4 \text{ nm}$$

- S.L. cruise: $R = 326\left(\frac{0.81}{0.39}\right)(6)\ln\left(\frac{1}{0.981}\right)$

$$R = 77.9 \text{ nm}$$

- total combat radius : 168 nm
- required " " : 120 nm

Ugly:

$$R = 326\left(\frac{0.81}{0.39}\right)(7)\ln\left(\frac{1}{0.985}\right)$$

$$R = 76.4 \text{ nm}$$

S.L. Cruise: $$R = 326\left(\frac{0.81}{0.39}\right)(7)\ln\left(\frac{1}{0.983}\right)$$

$$R = 81.3 \text{ nm}$$

total combat radius = 157 nm

required " " = 100 nm

Combat Ceiling:

Good $$R.C. = 500 = 60(250)\left[T/33{,}000 - \frac{1}{7}\right]$$

$$T = 6999 \Rightarrow P = \frac{T \cdot V}{550} = 3181 \text{ hp.}$$

from the performance diagrams: at 250 ft/s

$$\sigma = \frac{3181}{10{,}000} = 0.318 \Rightarrow h = 34{,}330 \text{ ft}$$

Bad $$RC = 500 = 60(250)\left[T/18{,}000 - \frac{1}{7}\right]$$

$$T = 3171 \text{ lb} \quad P = 1441 \text{ hp.}$$

from the performance diagrams at 250 ft/s

$$\sigma = \frac{1441}{4{,}000} = 0.360 \Rightarrow h = 31{,}000 \text{ ft}$$

Ugly: $$RC = 500 = 60(250)\left[T/8{,}500 - \frac{1}{7}\right]$$

$$T = 1497 \text{ lbs} \Rightarrow P = 680 \text{ hp}$$

from the performance diagrams at 250 ft/s

$$\sigma = \frac{680}{2000} = 0.3404 \Rightarrow h = 32{,}539 \text{ ft}$$

Endurance :

1) Good airplane : 1 hr @ 5,000 ft. V_{ltr} = 145 Kts. (assumed)

from Roskam, Pt. VII :

$$E = 778 \left(\frac{\eta_p}{c_p}\right)\sqrt{\rho S}\left(\frac{C_L^{3/2}}{C_D}\right)\left(\frac{1}{\sqrt{W_{end}}} - \frac{1}{\sqrt{W_{in.}}}\right)$$

W_i = 39,725 lbs (0.856) = 34,010 lbs

W_{end} = 34,010 lbs (0.98) = 33,345 lbs

$$C_L = \frac{33\,677}{61.2 \cdot 890} = 0.618$$

$$C_D = 0.0252 + 0.0496(0.618)^2 = 0.0442$$

So:

$$E = 778\left(\frac{0.86}{0.40}\right)\sqrt{(0.00204)(890)}\left(\frac{0.618^{1.5}}{0.0442}\right)\left(\frac{-1}{\sqrt{34{,}010}} + \frac{1}{\sqrt{33{,}345}}\right)$$

$$E = 1.33 \text{ hrs}$$

(meets requirement) (33% discrep)

	M_{ff}	W_f (lbs)
Old fuel fraction:	0.695	10,200
New fuel fraction:	0.743	8,620

SAVINGS : 1,580 lbs ⇒ 15.5% of old fuel weight.

T-O Groundrun

Bad airplane : 1,200 ft, soft field.

With 167.6 ft/s Lift-off speed ⇒ S_{TOG} = 1328 ft.

- to meet 1,200 ft requirement, the liftoff speed has to be :

$$V_{LOF} = 1.1 (V_s)$$

$$1200\left[\frac{9{,}858}{22{,}289} - 0.114\right] = V_{LOF}^2 / 64.4$$

$$V_{LOF} = 159.3 \text{ ft/s} \quad \text{or} \quad V_s = \frac{159.3}{1.1} = \underline{144.7 \text{ ft/s}}$$

this would require a C_L of:

$$C_{L_{\substack{max\\TO}}} = \frac{2(39{,}725)}{(0.002377)(890)(144.7)^2} = 1.79$$

which translates into a ΔC_L of : 0.39

which can be attained with the existing flaps

(landing C_L is 1.80).

APPENDIX C

The purpose of this appendix is to present the spreadsheet used in the calculation of the stability and control derivatives. The derivatives were calculated for 8 flight conditions.

Table of Contents

APPENDIX C:

To carry the calculations in an iterative method, the spreadsheet format is used. The following 24 tables are presented in Appendix C.

C.1 Lifting surface parameters
C.2 Fuselage cross-sectional parameters
C.3 Mach number dependent parameters

C.4.i Longitudinal and lateral-directional dimensional stability derivatives
C.5.i Longitudinal airplane transfer function
C.6.i Lateral-directional airplane transfer function

i = 1 Take-off
i = 2 Cruise #1, and loiter
i = 3 Cruise #2
i = 4 Dash-in
i = 5 Maneuver
i = 6 Dash-out
i = 7 Landing

A copy of References 1 through 8, and 10 are required to follow the method implemented into the spreadsheet.

HOW TO READ THE SPREADSHEET.

The spreadsheet format is simple to use. There are three standard line formats: Table C.1, Table C.2 and all the others.

Table C.1 presents the lifting surface parameters. In this table the following lifting surfaces are characterized: wing, horizontal and vertical tails, trailing edge flaps, aileron, elevator and rudder. Table C.1 header displays reference, unit, variable and the control surface of interest.

Under Reference the standard format is the following:

T8.1VI217 ---->> Table 8.1, Ref.VI, p.217
VI27 --------->> Ref.VI, p.27
F12.3II283 --->> Figure 12.3, Ref.II, p.283
(12.1)II284 -->> Equation (12.1), Ref.II, p.284
mgc ---------->> (description of the variable) mean geometric chord

There can be 9 different reference symbols:

I for DESIGN BOOK PART I, Ref.1.
II for DESIGN BOOK PART II, Ref.2.
III for DESIGN BOOK PART III, Ref.3.
IV for DESIGN BOOK PART IV, Ref.4.
V for DESIGN BOOK PART V, Ref.5.

VI for DESIGN BOOK PART VI, Ref.6.
VII for DESIGN BOOK PART VII, Ref.7.
one for AIRPLANE FLIGHT DYNAMICS PART I, Ref.8.
red for AIRPLANE AERODYNAMICS AND PERFORMANCE, Ref.10.

The reference symbol always precedes the page number.

In the format of Table C.1 the variable to the left applies to the lifting surfaces to the right. As an example the planform areas S are given as follow:

Reference	Unit	Variable	Wing____	H.tail____	V.tail____	TE.flaps____	(etc).
Areas	sqf	S	890	160	120	36.85	

In some cases the space is blank under a lifting surface. This means that there is no need for this variable in the analysis.

Table C.2 present the fuselage cross-sectional parameters. The GOOD airplane fuselage is sectionned into 13 sections for the aerodynamic analysis. Parameters such as cross-sectional area, perimeter, wet area, height, fuselage station, side area, width, etc. are tabulated under each fuselage cross-sections. References use the same format as mentionned above.

The possible units in the unit column are the following:

cu.ft	cubic feet
d	degree
/d	per degree
/d2 or /d^2	per degree square
fpm	feet per minute
fps	feet per second
ft	feet
ft/s2	feet per second square
hp	horse power
hp/sqf	horsepower per square foot
hr	hours
in	inches
kts	knots
n.m.	nautical miles
psf	pounds per square foot
psi	pounds per square inche
r	radian
/r	per radian
/(r.d)	per radian degree
r/s	radian per second
s	seconds
Sh/4	horizontal tail area divided by 4 (sqf)
slugs	slugs
slug.sqf	slugs per square foot
sqf	square feet
sqi	square inches

VA	volt ampere
#	pounds
#/gal	pounds per gallon
#/hp/hr	pounds per horse power per hour
#/hr	pounds per hour
#/s	pounds per second
slug/ft3	slugs per cubic foot
#/h/shp	pounds per hour per shaft horse power
#s/sqf	pounds seconds per square foot
%	percent
[blank]	dimensionless
[other]	description

When more than one unit figure on the same line the variable values to the right appear in unit order. As an example in Table C.1 the span for the lifting surfaces reads as follow:

Reference	Unit	Variable	Wing____		H.tail____		V.tail____		TE.flaps____	(etc).
Span	in,ft	b	1010	84.3	346	28.8	124	10.33		

The left value under each lifting surface is in inches (b = 1010 in, b = 346 in, b = 124 in). The right value under each lifting surfacewis in feet (bh= 84.3 ft, b = 28.8 ft, b = 10.33 ft). The same method applies for r,d (degrew, radian), khs,fpm (knotsv feet per minute), etc.

In all other Tables (Table C.3, Tables C.4.1-7, C.5.1-7 and C.6.1-7) the standard line format is the following:

Example 1.:

Reference	**Units**	**Variable**	**Given**	**Measured**	**Computed**	**M=0.0 .....M=0.9**
(6.5)V85	#	Wsprch			1505	

Example 1 reads as follow: Equation (6.5), Reference Design Book Part V, page.85, is used to compute the supercharger weight variable W_{sprch}. The computed value is 1,505 lbs, (# under units for pounds).

Example 2.:

Reference	**Units**	**Variable**	**Given**	**Measured**	**Computed**	**M=0.0......M=0.9**
I7	%,#	%WTO,Wtfo	0.500		197	

Example 2 reads as follow: Reference Design Book Part I, page 7, the units are: to the left a percentage, and to the right pounds; the variables are a percentage of the take-off weight W_{TO}, (explained in the reference), and the weight of all trapped (=unusable) fuel and oil W_{tfo}. The given value 0.500 is an input for %WTO, and 197 lbs is the computed value for Wtfo.

Example 3:

Reference	**Units**	**Variable**	**Given**	**Measured**	**Computed**	**M=0.0......M=0.9**

```
Vertical tail ........>> (5.13)  (5.15)  (5.18) ... (ave)
V71-74      #   Wv....>>   98      198      392  ...  229
```

Example 3 reads as follow: Equations (5.13), (5.15), and (5.18) from Reference Design Book Part V, on pages 71 to 74 are used to compute the vertical tail weight. The units are pounds, the variable is W_v. The computed value with equation (5.13) is 98 pounds, the computed value with Eqn.(5.18) is 392 pounds, etc.

There is a computed average value under (ave). Considering the aircraft analyzed, the appropriate equation values are averaged and the vertical tail weight results. The average value is directly fed to the weight and balance section of the spreadsheet.

Note that the weight estimation section of table C.3 was not used for the GOOD airplane, but, since it is an integral part of the spreadsheet program, and that other variables are inserted within the weight section it is presented. The reader must be aware that not all the variables of Table C.3 are used in the computation of the GOOD airplane aerodynamic characteristics. The performance characteristics of Table C.3 must not be regarded as verified values.

SPECIAL NOTICES ABOUT THE SPREADSHEET:

Values given in different sections of the spreadsheets may be:

1.1) **GIVEN** values
1.2) **MEASURED** values
1.3) **COMPUTED** values
1.4) **MACH DEPENDENT** values
1.5) **LIFTING SURFACE DEPENDENT** values
1.6) **FUSELAGE CROSS-SECTION DEPENDENT** values
1.7) **EQUATION DEPENDENT** values

Always refer to the first title above the value.

Despite the title of Table C.3 "Mach Number Dependent Parameters", there are many variables in that table which are not Mach number dependent.

Table C.1 LIFTING SURFACE PARAMETERS

Reference	Unit	Variable	wing		H.tail		V.tail		TE.flaps	aileron	elevator		rudder
T8.1VI217	NACA	airfoil	642A215		641012		641012						
VI27		A		8		5.1960		0.8898					
T8.1cVI217		a.c.		0.252									
T8.1VI216	d	aclmax	15										
T8.1VI216	d,r	aol	-2	-0.034									
Span	in,ft	b	1010	84.380	346	28.833	124	10.333					
mgc	in,ft	c[-]	132	11	60	5	69	5.75			21	1.75	
VI230,447		ci/cj							cf/c == 0.296	ca/c == 0.305	ce/ch==	0.35	
IV215R2p30	/d,/r	cla	0.095	5.4430	0.1062	6.0876	0.1062	6.0876					
VI230		cla/clath		0.8662		0.9688		0.9688					
T8.1VI217		clmax		1.5									
T8.1cVI217		cmo		-0.04									
VI428		cos(sweep1/4)		0.9762									
VI376		cos(sweep1/4)^2		0.9531									
		cos(sweep1/2)		0.9890									
Root chord	in,ft	cr	202.8	16.9	62	5.1666	83	6.9166					
Tip chord	in,ft	ct	50.4	4.2	42	3.5	56	4.6666					
VI29	d,r	et	-2	-0.034	0	0							
VI392	d	et tan(sweep c/4)		-4E-01		0E+00							
Incidence	d,r	i(w,h,,p)	0	0	0	0							
F3.12one72		K		1.0613		1.0705		1.0166					
Taper ratio		lambda		0.25		0.6774		0.6746					
L.E. sweep	d,r	lambda LE	16	0.2792	0	0	24.5	0.4276					
c/4 sweep	d,r	lambda 1/4	12.5	0.2181	0	0	22	0.3839					
c/2 sweep	d,r	lambda 1/2	8.5	0.1483	0	0	19	0.3316					
Areas	sqf	S		890		160		120	36.85	10.78		21.67	11.78
Area ratio		S(h,v,p)/S				0.1797		0.1348					
F10.7VI382	d,r	Dihedral	0	0	0	0	gamma						
F12.3II283	sqf	Sexp.plf		789.86		160		120					
(12.1)II284	sqf	Swet.plf		1638.9		329.6		247.2					
Root thickness ratio		(t/c)r		0.15		0.12		0.12					
Tip thickness ratio		(t/c)t		0.15		0.12		0.12					
		tan(sweep1/4)		0.2216		0							
VI428,248		tan2(sweep1/4)		0.0491									
		tan2(sweep1/2)		0.0223		0		0.1185					
(t/c)r/(t/c)t		tau		1		1		1					
V69,73,72	in,ft	tr	30.42	2.535	7.44	0.62	9.96	0.83					

Table C.2 FUSELAGE CROSS-SECTIONAL PARAMETERS

Fuselage cross-sections:			<1>	<2>	<3>	<4>	<5>	<6>	<7>	<8>	<9>	<10>	<11>	<12>	<13>	<tail>
Cross-s.area	sqf	Sxi	3.0106	14.551	24.445	21.380	20.616	25.525	24.216	19.853	17.638	15.637	12.664	10.471	7.6576	
Perimeter	ft	Pfi	6.1522	13.613	17.933	16.493	16.100	18.064	17.540	15.969	15.053	14.137	12.697	11.519	9.8174	8.5084
Wet area	sqf	Swetfusi	8.4901	45.461	72.557	79.181	74.966	106.19	139.45	73.885	15.296	14.392	13.230	11.940	10.520	4.5178
F10.10VI385	ft	dSxi/dxi	1.3089	2.5089	2.1508	-0.666	-0.165	0.7896	-0.167	-0.989	-2.245	-2.029	-3.014	-2.223	-2.853	
"	ft	xl	0	0	0	0	0	0	0	0	0	0	42.118	0	0	
Height	ft	hfi	1.9166	4.8333	6.9166	5.8333	5.25	5	5	4.3333	4.0833	3.9166	3.5833	3.3333	3	2.6666
Fusel.station	ft	F.S.	2.3	6.9	11.5	16.1	20.7	26.916	34.75	39.159	40.145	41.131	42.118	43.104	44.090	44.583
Side areas	sqf	Sside(i)	2.4245	15.603	27.160	29.472	25.619	32.020	39.363	20.682	4.1707	3.9642	3.7164	3.4274	3.1383	1.4040
F8.116VI327	ft	^xi	4.6	4.6	4.6	4.6	4.6	7.8333	7.8333	0.9861	0.9861	0.9861	0.9861	0.9861	0.9861	
"	ft	^x15,cf,^x813		23	15.666	5.9166										
"	ft	xi	20.7	16.1	11.5	6.9	2.3	11.75	3.9166	0.4930	1.4791	2.4652	3.4513	4.4375	5.4236	
"	ft	Wfi	2	3.8333	4.5	4.6666	5	6.5	6.1666	5.8333	5.5	5.0833	4.5	4	3.25	2.75
"		xi/cf	1.3212	1.0276	0.7340	0.4404	0.2936									
F8.112VI321	d	iclfi	-11	-14	-17	-11	-6	0	3	-22	-1	-2	-12	-19	-19	
	r	iclfi	-0.191	-0.244	-0.296	-0.191	-0.104	0	0.0523	-0.383	-0.017	-0.034	-0.209	-0.331	-0.331	

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
T2.15I47		A	0.2705														
T1.1red11	fps	a	1116.4	Speed of sound @ 0 ft													
alpha	d	a				-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
(4.34)VI46	r	a	a=f(M,...)				2.5992	0.6310	0.2666	0.1390	0.0799	0.0478	0.0284	0.0158	0.0071	0.0030	0.0014
"	d	a					148.92	36.159	15.275	7.9652	4.5807	2.7412	1.6308	0.9088	0.4124	0.1734	0.0855
airfoil,wing	d	a*,a*new	12		12.022												
Wing	r,d	aCLmax		0.2621	15.022												
VI394		A/cos(lambda1/2)			8.0888												
I10	fps	a(cruise)	1097.1	Speed of sound at 5000 ft													
(10.109)VI446		ada			0.6760												
(10.94)VI437		ade,adeCL/adecl			0.2418	1.0351											
F8.53VI261		(ade)cl			0.7189												
(10.66)VI422		adf			0.4191												
F8.17VI230		adf	0.44														
VII164		a[-]/g	0.45														
T5.1V82		Agm,Agn	33	12													
V88	sqi,sqf	Ainl		374.4	2.6												
VII133	d,r	alpha(cruise)		0	0												
F8.41VI247wing		^ao/et		-0.356													
(8.21)VI245	r	aoLw				-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.020	-0.016
F8.42VI247		(ao)M/(ao)M=i				1	1	1	1	1	1	1	1	1	1	0.9	0.75
F10.19VI391		Aveff			1.3429												
(10.64)VI422		B				1	0.9988	0.9952	0.9892	0.9807	0.9697	0.9561	0.9398	0.9205	0.8983	0.8727	0.8436
T2.15(I)47		B	0.983														
(10.53)VI417		B				1	0.9987	0.9949	0.9886	0.9797	0.9682	0.9539	0.9367	0.9165	0.8930	0.8660	0.8351
"		B^2				1	0.9975	0.99	0.9775	0.96	0.9375	0.91	0.8775	0.84	0.7975	0.75	0.6975
F10.35VI418		BA/k(wing)				9.2347	9.2116	9.1423	9.0269	8.8653	8.6575	8.4035	8.1034	7.7571	7.3646	6.9260	6.4412
"		BAh/kh(h.tail)					5.3494	5.3092	5.2422	5.1483	5.0276	4.8802	4.7059	4.5048	4.2768	4.0221	3.7406
F10.46VI443	/r	BC'ld/k		0.375													
F10.35VI418		(BClp/K)CL=0(wing)			figure	-0.475	-0.473	-0.472	-0.47	-0.468	-0.467	-0.465	-0.448	-0.431	-0.413	-0.396	-0.379
"		(BClp/K)CL=0(h.tail)			figure		-0.4	-0.394	-0.389	-0.383	-0.377	-0.371	-0.366	-0.36	-0.336	-0.312	-0.288
VI423	in,	bf,bf/b		556	0.5504												
T5.1V82		Bgm,Bgn	0.04	0.06													
F10.17VI390		bh/lf			0.6467												
F10.18VI391	in,ft	bv'		124	10.333												
F10.19VI391		bv'/bv			1												
(5.2)VIp128		CD					6.8970	0.4524	0.1080	0.0502	0.0344	0.0287	0.0263	0.0252	0.0245	0.0242	0.0240

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
"		CD			CL = 0.3		0.0279	0.0278	0.0278	0.0278	0.0278	0.0278	0.0277	0.0277	0.0277	0.0276	0.0276
"		CD			CL = 0.9		0.0623	0.0622	0.0621	0.0620	0.0618	0.0615	0.0612	0.0609	0.0605	0.0601	0.0597
			CDo	1/piAe	e												
Rep4	TO & Land	CD clean	0.0222	0.0497	0.8		7.1688	0.4688	0.1104	0.0501	0.0336	0.0277	0.0251	0.0239	0.0232	0.0229	0.0226
	TO	CDflapsGU	0.0322	0.0530	0.75												
	"	CDflapsGD	0.0522	0.0530	0.75												
	Lan	CDflapsGU	0.0472	0.0568	0.7												
	"	CDflapsGD	0.0672	0.0568	0.7												
	cruise	CD clean	0.0213	0.0497	0.8												
	"	CD+stores	0.0252	0.0497	0.8												
(10.18)VI379	/r	CDa					5.2479	1.3191	0.5916	0.3371	0.2194	0.1556	0.1173	0.0925	0.0757	0.0638	0.0553
"	/r	CDa			CL = 0.3		0.1313	0.1320	0.1332	0.1350	0.1373	0.1402	0.1438	0.1482	0.1535	0.1599	0.1675
"	/r	CDa			CL = 0.9		0.3940	0.3961	0.3998	0.4050	0.4119	0.4207	0.4315	0.4447	0.4606	0.4797	0.5027
(10.21)VI381		CDa[.]	0														
VII126		CDclimb Low S			0.0624												
VII133		CDcr+stores			0.0307												
(10.93)VI437	/r	CDdE					0	0	0	0	0	0	0	0	0	0	0
(10.89)VI435	/r	CDih					0	0	0	0	0	0	0	0	0	0	0
VII142		CDltr			0.0433												
(5.1)VI128	/r	CDo			0.0235												
(4.6)VI23		CDow					0.0088	0.0075	0.0066	0.0059	0.0058	0.0057	0.0056	0.0058	0.0059	0.0058	0.0059
VII44		CD(TO)			0.1561												
(10.10)VI376		CDu					-6.444	-6.788	-0.603	-0.147	-0.053	-0.024	-0.012	-0.007	-0.004	-0.002	-0.001
F5.20VI129		Cf	0.004														
F4.3VI25		Cfw			figure>>		0.0035	0.0031	0.0029	0.0026	0.0026	0.0025	0.0024	0.0024	0.0024	0.0023	0.0023
T5.1V82		Cgm,Cgn	0.021	0													
(5.22,24)VII126,127		CGR		0.6361	0.3207												
f(a)CLa@M=.35		CL				-0.422	-0.335	-0.247	-0.160	-0.072	0.0144	0.1019	0.1894	0.2769	0.3644	0.4518	0.5393
40 deg plain flaps		CL+^cl				1.1699	1.2574	1.3449	1.4324	1.5198	1.6073	1.6948	1.7823	1.8697	1.9572	2.0447	2.1322
(8.4)VI226		^cl			1.5928												
(10.6)VI374		CL1					11.987	2.9967	1.3319	0.7491	0.4794	0.3329	0.2446	0.1872	0.1479	0.1198	0.0990
(5.68)VII153		CL1			0.2097												
f(a)CLa@M=.2		CL1			CL(a)==	-0.397	-0.315	-0.233	-0.151	-0.068	0.0131	0.0952	0.1773	0.2594	0.3415	0.4236	0.5057
(8.42)VI272	/d	CLa				0.0797	0.0798	0.0803	0.0810	0.0821	0.0835	0.0852	0.0874	0.0901	0.0933	0.0972	0.1019
	/r	CLa				4.5678	4.5761	4.6012	4.6436	4.7042	4.7844	4.8862	5.0120	5.1651	5.3499	5.5720	5.8386
(10.22)VI381	/r	CLa[.]					1.4428	1.4585	1.4851	1.5236	1.5752	1.6418	1.7259	1.8307	1.9609	2.1224	2.3236
	/d	CLah				0.0689	0.0690	0.0693	0.0699	0.0707	0.0718	0.0731	0.0748	0.0768	0.0791	0.0819	0.0852

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
(8.22)VI248	/r	CLah				3.9483	3.9547	3.9741	4.0068	4.0535	4.1149	4.1923	4.2871	4.4012	4.5370	4.6974	4.8857
VI419	/r	(CLah)CL=0			4.3150												
(8.42)VI272	/r	CLaP				0	0	0	0	0	0	0	0	0	0	0	0
	/d	CLav				0.0323	0.0326	0.0327	0.0328	0.0329	0.0330	0.0331	0.0333	0.0335	0.0338	0.0340	0.0343
(8.22)VI248	/r	CLav				1.8527	1.8729	1.8754	1.8795	1.8853	1.8927	1.9016	1.9120	1.9237	1.9368	1.9510	1.9660
	/d	CLaw				0.0715	0.0717	0.0721	0.0728	0.0738	0.0752	0.0769	0.0791	0.0817	0.0849	0.0888	0.0934
(8.22)VI248	/r	CLaw				4.1005	4.1086	4.1328	4.1739	4.2328	4.3109	4.4102	4.5335	4.6842	4.8670	5.0881	5.3558
VI419	/r	(CLaw)CL=0			4.5789												
	/d	CLawf				0.0716	0.0717	0.0721	0.0728	0.0739	0.0752	0.0770	0.0791	0.0818	0.0849	0.0888	0.0935
(8.43)VI272	/r	CLawf				4.1030	4.1110	4.1353	4.1764	4.2354	4.3135	4.4129	4.5362	4.6870	4.8699	5.0912	5.3590
(10.33)VI389	/r	ClB					-0.355	-0.041	-0.041	-0.042	-0.043	-0.043	-0.043	-0.044	-0.044	-0.044	-0.044
"	/r	ClB			CLwf = 0.3		0.0882	0.0593	-0.003	-0.026	-0.037	-0.043	-0.047	-0.050	-0.052	-0.053	-0.054
"	/r	ClB			CLwf = 0.9		0.0611	0.0323	-0.030	-0.054	-0.065	-0.071	-0.076	-0.079	-0.082	-0.084	-0.086
F10.23VI394	/d	(ClB/CL)A(wing,H.tail)			0.0001	-0.001											
F10.20VI393	/d	(ClB/CL)sweep1/2 (wing,H.tail)				-9E-04	0E+00										
F10.26VI396	/d2	^ClB/et[tan(sweep1/4)](wing,H.tail)					-3E-05	-3E-05									
F10.24VI395	/d^2	ClB/gamma(wing,H.tail)			-2E-04	-2E-04											
(10.35)VI392	/d^2	^ClB/gamma(wing,H.tail)			-1E-05	-1E-04											
(10.38)VI397	/r	ClBh					-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017
VI397	/r	ClBhf					-0.279	-0.279	-0.279	-0.279	-0.279	-0.279	-0.279	-0.279	-0.279	-0.279	-0.279
(10.39)VI397	/r	ClBv					0.1145	0.0856	0.0229	-0.000	-0.011	-0.017	-0.020	-0.023	-0.024	-0.025	-0.026
(10.34)VI392	/r	ClBwf					-0.453	-0.110	-0.047	-0.025	-0.014	-0.009	-0.006	-0.004	-0.002	-0.001	-0.000
"	/r	ClBwf			CLwf = 0.3		-0.009	-0.009	-0.009	-0.009	-0.009	-0.009	-0.009	-0.010	-0.010	-0.010	-0.011
"	/r	ClBwf			CLwf = 0.9		-0.036	-0.036	-0.036	-0.036	-0.037	-0.037	-0.038	-0.039	-0.040	-0.041	-0.043
(10.37)VI397	/d	(^ClB)zw(wing,H.tail)			6E-05	-0.004											
Trim diagram		CL+^CLctl				-0.324	-0.236	-0.149	-0.061	0.0256	0.1130	0.2005	0.2880	0.3755	0.4629	0.5504	0.6379
"		CL-^CLctl				-0.521	-0.434	-0.346	-0.259	-0.171	-0.084	0.0033	0.0908	0.1783	0.2658	0.3532	0.4407
VII126		CLclimb	0.9														
(5.39)VII137		CLcr1			0.3301												
(5.29,30)VII133		CLcr			0.3329	0.3329											
(8.113)VI346		^CLctl					0.0909	0.0913	0.0921	0.0932	0.0946	0.0964	0.0985	0.1012	0.1043	0.1080	0.1123
(10.110,108)VI446	/r	clda,Clda		3.68			0.2201	0.2218	0.2246	0.2287	0.2342	0.2413	0.2502	0.2614	0.2754	0.2928	0.3148
(10.107)VI446	/r	C'lda					0.3256	0.3281	0.3323	0.3383	0.3465	0.3569	0.3702	0.3867	0.4073	0.4331	0.4657
(10.95)VI438	/r	CLde					0.1736	0.1745	0.1759	0.1780	0.1807	0.1841	0.1882	0.1933	0.1992	0.2063	0.2145
(10.124)VI461	/r	Cldr					-0.072	-0.054	-0.014	0.0001	0.0070	0.0107	0.0130	0.0146	0.0157	0.0163	0.0166
"	/r	Cldr			CL = .25		0.0128	0.0128	0.0128	0.0128	0.0129	0.0130	0.0130	0.0131	0.0132	0.0133	0.0134
"	/r	Cldr			CL = .75		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
F8.15VI230		cld/cldth(elev,flap,aile,rudder)					0.96	0.8	0.8	0.95							
F8.14VI228	/r	(cld)th(elev,flap,aile,rudder)				4.78	4.6	4.6	4.55								
(8.119,90)VI352,436		^CLh,CLh					0	0	0	0	0	0	0	0	0	0	0
VII44		CLhmax	-1.7														
	/d	CLih					0.0125	0.0125	0.0126	0.0128	0.0130	0.0132	0.0135	0.0139	0.0143	0.0148	0.0154
(10.91)VI436	/r	CLih					0.7180	0.7215	0.7275	0.7360	0.7471	0.7612	0.7784	0.7991	0.8238	0.8529	0.8871
(3.11)VI20		CL(L/D)max			0.7023												
(5.42)VII141		CLltr			0.6524												
(5.67)VII153		CLmaneuver			1.5373												
			wing	Clean	T-Off	Land	Manen										
T3.1I91,VI217		CLmax	1.565	1.3	1.4	1.5	1.5										
(8.32)VI268		CLo					0.0924	0.0929	0.0938	0.0952	0.0969	0.0992	0.1019	0.1053	0.1094	0.1030	0.0903
VI322		CLoh					0	0	0	0	0	0	0	0	0	0	0
(8.33)VI268		CLouf					0.0924	0.0929	0.0938	0.0952	0.0969	0.0992	0.1019	0.1053	0.1094	0.1030	0.0903
(10.51)VI417	/r	Clp					-1.414	-0.445	-0.400	-0.401	-0.415	-0.434	-0.445	-0.461	-0.483	-0.514	-0.556
F10.36VI420		(CLp)CDL/(CL)^2		-0.01													
(10.55)VI419		(Clp)Dih/(Clp)Dih=0(wing)				1											
"		(Clp)Dih/(Clp)Dih=0(H.tail)				1											
(10.56)VI419	/r	(^Clp)drag					-1.029	-0.065	-0.013	-0.004	-0.002	-0.001	-0.001	-0.001	-0.000	-0.000	-0.000
(10.59)VI421	/r	Clph___0.5Sh/S(bh/b)2			0.0104		-0.014	-0.004	-0.004	-0.004	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
(10.52)VI417	/r	(Clp)h					-1.413	-0.459	-0.402	-0.387	-0.379	-0.372	-0.367	-0.361	-0.336	-0.312	-0.288
(10.60)VI421	/r	Clpv				-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
(10.52)VI417	/r	Clpw					-1.397	-0.438	-0.393	-0.395	-0.408	-0.427	-0.439	-0.455	-0.477	-0.509	-0.551
(10.69)VI424	/r	CLq				0.6917	4.7874	4.8095	4.8468	4.8999	4.9699	5.0580	5.1661	5.2962	5.4513	5.6346	5.8502
(10.72)VI425	/r	CLqh				0	4.0950	4.1151	4.1490	4.1973	4.2609	4.3410	4.4392	4.5574	4.6980	4.8640	5.0591
"	/r	CLqp				0	0	0	0	0	0	0	0	0	0	0	0
(10.70)VI424	/r	CLqw				0.6917	0.6923	0.6943	0.6977	0.7025	0.7089	0.7169	0.7268	0.7388	0.7532	0.7705	0.7911
(10.71)VI424	/r	(CLqw)M=0			0.6917												
(10.81)VI428	/r	Clr					2.6033	0.6697	0.3681	0.2656	0.2183	0.1927	0.1773	0.1675	0.1609	0.1557	0.1514
"	/r	Clr			CL = .25		0.1811	0.1813	0.1817	0.1821	0.1827	0.1835	0.1845	0.1857	0.1872	0.1889	0.1911
"	/r	Clr			CL = .75		0.2878	0.2883	0.2892	0.2905	0.2921	0.2943	0.2970	0.3003	0.3044	0.3095	0.3157
F10.43VI431	/(r.d)	^Clr/adfdf		0.0048													
(10.83)VI428	/r	(Clr/CL)CL=0,M					0.2402	0.2409	0.2420	0.2437	0.2460	0.2489	0.2525	0.2569	0.2624	0.2691	0.2774
F10.41VI430	/r	(Clr/CL)CL=0,M=0		0.24													
F10.42VI430	/(r.d)	^Clr/et		-0.013													
(10.84)VI429		^Clr/gamma			0.0440												
(10.85)VI429	/r	Clrv					0.0601	-0.051	-0.015	0.0001	0.0074	0.0113	0.0136	0.0151	0.0161	0.0166	0.0168

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
"	/r	Clrv			CL = .25		0.0136	0.0136	0.0136	0.0137	0.0137	0.0138	0.0139	0.0140	0.0141	0.0142	0.0143
"	/r	Clrv			CL = .75		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
(10.82)VI428	/r	Clrw					2.5432	0.7208	0.3834	0.2654	0.2109	0.1813	0.1637	0.1523	0.1447	0.1390	0.1346
"	/r	Clrw			CL = .25		0.1675	0.1677	0.1680	0.1684	0.1689	0.1697	0.1706	0.1717	0.1730	0.1747	0.1768
"	/r	Clrw			CL = .75		0.2876	0.2881	0.2890	0.2903	0.2920	0.2941	0.2968	0.3002	0.3043	0.3093	0.3155
(10.11)VI376		CLu					0.0286	0.0288	0.0291	0.0296	0.0303	0.0312	0.0323	0.0337	0.0353	0.0374	0.0401
(10.57)VIp419		CLw					10.139	2.5458	1.1398	0.6478	0.4203	0.2969	0.2226	0.1747	0.1421	0.1173	0.0977
VI392		CLwf					10.139	2.5458	1.1398	0.6478	0.4203	0.2969	0.2226	0.1747	0.1421	0.1173	0.0977
Trim diagram		Cm	@ M=0.4				-0.001	-0.007	-0.013	-0.019	-0.025	-0.031	-0.037	-0.043	-0.049	-0.055	-0.061
one413		Cml					-0.050	-0.035	-0.032	-0.031	-0.031	-0.031	-0.031	-0.031	-0.032	-0.033	-0.033
(10.19)VI381	/r	Cma			Xcg(fwrd)		-0.428	-0.425	-0.419	-0.412	-0.401	-0.386	-0.367	-0.341	-0.309	-0.264	-0.204
"	/r	Cma			Xcg(aft)		-0.016	-0.011	-0.002	0.0111	0.0292	0.0529	0.0837	0.1231	0.1717	0.2367	0.3209
"	/d	Cma					-0.007	-0.007	-0.007	-0.007	-0.007	-0.006	-0.006	-0.005	-0.005	-0.004	-0.003
(10.24)VI382	/r	Cma[.]					-3.984	-4.027	-4.101	-4.207	-4.350	-4.533	-4.765	-5.055	-5.414	-5.861	-6.416
(8.116)VI349		^Cm(cg(aft,forw)-ref)			-0.089	0											
Trim diagram		Cm+^Cmctl			@ M=0.4		-0.290	-0.296	-0.302	-0.308	-0.314	-0.320	-0.326	-0.332	-0.338	-0.344	-0.350
Trim diagram		Cm-^Cmctl			@ M=0.4		0.2866	0.2806	0.2746	0.2687	0.2627	0.2567	0.2508	0.2448	0.2389	0.2329	0.2269
(8.114)VI346		^Cmctl					-0.259	-0.260	-0.262	-0.265	-0.269	-0.274	-0.281	-0.288	-0.297	-0.308	-0.320
(10.96)VI438	/r	Cmde					-0.495	-0.497	-0.501	-0.507	-0.515	-0.525	-0.536	-0.551	-0.568	-0.588	-0.611
(10.92)VI436	/r	Cmih					-2.047	-2.057	-2.074	-2.098	-2.130	-2.170	-2.219	-2.278	-2.349	-2.432	-2.529
(8.76)VI320		Cmo					-0.030	-0.030	-0.030	-0.030	-0.030	-0.031	-0.031	-0.031	-0.032	-0.033	-0.033
F8.98VI304	/d	^cmo/et		-0.003													
(8.78)VI320		Cmof				-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
(8.79)VI322		Cmoh					0	0	0	0	0	0	0	0	0	0	0
F8.99VI306		(Cmo)M/(Cmo)M=0				0.9997	1.0022	1.0011	0.9989	0.9978	0.9995	1.0053	1.0156	1.0308	1.0505	1.0741	1.1010
VI302	642A215	cmor,cmot	-0.04	-0.04													
(8.77)VI320		Cmowf					-0.030	-0.030	-0.030	-0.030	-0.030	-0.031	-0.031	-0.031	-0.032	-0.033	-0.033
(8.71)VI305		CmowM					-0.030	-0.030	-0.030	-0.030	-0.030	-0.030	-0.031	-0.031	-0.032	-0.032	-0.033
(8.70)VI302		CmowM=0			-0.030												
(10.75)VI425	/r	Cmq				-0.774	-12.45	-12.51	-12.61	-12.75	-12.94	-13.18	-13.47	-13.82	-14.24	-14.73	-15.31
(10.78)VI426	/r	Cmqh				0	-11.67	-11.73	-11.83	-11.96	-12.14	-12.37	-12.65	-12.99	-13.39	-13.86	-14.42
(10.79)VI426	/r	Cmqp				0	0	0	0	0	0	0	0	0	0	0	0
(10.76)VI425	/r	Cmqw				-0.774	-0.775	-0.777	-0.781	-0.787	-0.795	-0.804	-0.816	-0.830	-0.847	-0.868	-0.893
(10.77)VI426	/r	Cmqw/at M=0			-0.774												
		CmT1															
(10.16)VI378		CmTu					1.0682	-0.441	-0.032	-0.012	-0.007	-0.005	-0.005	-0.004	-0.004	-0.004	-0.004
(10.12)VI377		Cmu					0.2787	0.1178	0.0749	0.0558	0.0454	0.0390	0.0349	0.0309	0.0307	0.0299	0.0290

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
"		Cmu			CL = 0.3		0.0069	0.0117	0.0168	0.0223	0.0284	0.0351	0.0428	0.0495	0.0622	0.0748	0.0878
"		Cmu			CL = 0.9		0.0209	0.0353	0.0506	0.0671	0.0852	0.1054	0.1285	0.1487	0.1868	0.2245	0.2634
F8.130VI343		{(CNa)pi}KNi=80.7		0.25													
(11.8)II265	/r	CnB	Sv/4	30	Stores, Clean		0.0211	-0.008	0.0213	-0.011	0.0214	-0.012	0.0217	-0.013	0.0220	-0.014	0.0223
&	"	"	Sv/2	60			0.0423	0.0124	0.0426	0.0101	0.0429	0.0091	0.0434	0.0084	0.0440	0.0074	0.0447
F10.16VI390	"	"	3Sv/4	90		M=0.1	0.0635	0.0336	0.0639	0.0314	0.0644	0.0306	0.0652	0.0302	0.0661	0.0294	0.0671
"	"	"	Sv	120		M=0.6	0.0847	0.0849	0.0852	0.0855	0.0859	0.0864	0.0869	0.0875	0.0881	0.0888	0.0895
"	"	"	5Sv/4	150			0.1059	0.1061	0.1065	0.1069	0.1074	0.1080	0.1086	0.1094	0.1102	0.1110	0.1119
"	"	"	3Sv/2	180			0.1271	0.1274	0.1278	0.1283	0.1289	0.1296	0.1304	0.1312	0.1322	0.1332	0.1343
"	"	"	7Sv/4	210			0.1483	0.1486	0.1491	0.1496	0.1503	0.1512	0.1521	0.1531	0.1542	0.1554	0.1567
"	"	"	2Sv	240			0.1695	0.1698	0.1704	0.1710	0.1718	0.1728	0.1738	0.1750	0.1763	0.1777	0.1791
(10.40)VI397	/r	CnB					-0.169	0.1303	0.1489	0.1502	0.1496	0.1496	0.1499	0.1499	0.1502	0.1506	0.1517
"	/r	CnB			CL = 0.25		0.1518	0.1506	0.1492	0.1491	0.1487	0.1492	0.1499	0.1502	0.1507	0.1512	0.1524
"	/r	CnB			CL = 0.75		0.1529	0.1517	0.1504	0.1502	0.1499	0.1504	0.1511	0.1514	0.1518	0.1524	0.1536
(10.42)VI398	/r	CnBf	<-- Clean				-0.028	-0.029	-0.031	-0.032	-0.033	-0.033	-0.034	-0.034	-0.035	-0.036	-0.036
"		CnBf	<-- stores				0	0	0	0	0	0	0	0	0	0	0
(10.43)VI398	/r	CnBv					-0.140	0.1602	0.1806	0.1826	0.1830	0.1834	0.1841	0.1849	0.1860	0.1872	0.1886
"	/r	CnBv			CL = 0.25		0.1803	0.1805	0.1809	0.1815	0.1822	0.1831	0.1841	0.1852	0.1865	0.1878	0.1893
"	/r	CnBv			CL = 0.75		0.1814	0.1817	0.1821	0.1826	0.1834	0.1842	0.1852	0.1864	0.1876	0.1890	0.1905
(10.41)VI398	/r	CnBw			0												
(10.114)VI448	/r	Cnda					-0.234	-0.059	-0.026	-0.015	-0.010	-0.007	-0.005	-0.004	-0.004	-0.003	-0.003
"	/r	Cnda			CLw = 0.3		-0.006	-0.006	-0.007	-0.007	-0.007	-0.007	-0.007	-0.008	-0.008	-0.009	-0.009
"	/r	Cnda			CLw = 0.9		-0.020	-0.020	-0.021	-0.021	-0.022	-0.022	-0.023	-0.024	-0.026	-0.027	-0.029
(10.125)VI462	/r	Cndr					0.0888	-0.101	-0.114	-0.115	-0.115	-0.115	-0.116	-0.116	-0.117	-0.118	-0.119
(4.6)V32		CNmax+			1.7215												
(10.61)VI421	/r	Cnp					0.0465	-0.083	-0.039	-0.013	0.0035	0.0173	0.0294	0.0406	0.0510	0.0605	0.0694
"	/r	Cnp			CL = .25		0.0370	0.0369	0.0369	0.0368	0.0366	0.0365	0.0362	0.0360	0.0357	0.0353	0.0349
"	/r	Cnp			CL = .75		0.0810	0.0808	0.0806	0.0803	0.0798	0.0793	0.0786	0.0778	0.0768	0.0757	0.0744
(10.65)VI422	/r	(Cnp/CL)CL=0,M=0					-0.115	-0.115	-0.115	-0.115	-0.114	-0.114	-0.114	-0.114	-0.114	-0.114	-0.113
(10.63)VI421		(Cnp/CL)CL=0,M					-0.115	-0.114	-0.114	-0.114	-0.113	-0.113	-0.112	-0.111	-0.110	-0.109	-0.107
F10.37VI420	/(r.d)	Cnp/et		0.0004													
F10.38VI423	/(r.d)	^Cnp/adfdf		0.0007													
(10.67)VI422	/r	Cnpv					0.0734	-0.066	-0.032	-0.017	-0.009	-0.005	-0.003	-0.001	-0.000	-0.000	-0.000
"	/r	Cnpv			CL = .25		-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
"	/r	Cnpv			CL = .75		-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017	-0.017
(10.62)VI421	/r	Cnpw					-0.026	-0.016	-0.006	0.0033	0.0133	0.0232	0.0330	0.0425	0.0519	0.0609	0.0696
"	/r	Cnpw			CL = .25		0.0404	0.0404	0.0403	0.0402	0.0401	0.0400	0.0398	0.0395	0.0392	0.0389	0.0385

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
"	/r	Cnpw			CL = .75		0.0980	0.0979	0.0977	0.0974	0.0970	0.0965	0.0960	0.0953	0.0944	0.0934	0.0923
(10.86)VI432	/r	Cnr					-0.077	-0.098	-0.123	-0.125	-0.125	-0.125	-0.125	-0.126	-0.126	-0.127	-0.128
"	/r	Cnr			CL = .25		-0.124	-0.124	-0.124	-0.124	-0.124	-0.125	-0.125	-0.126	-0.127	-0.128	-0.129
"	/r	Cnr			CL = .75		-0.125	-0.125	-0.125	-0.125	-0.126	-0.126	-0.127	-0.128	-0.129	-0.130	-0.131
F10.45,44VI434,433	/r	(Cnr/CDo),(Cnr/CL^2)			-0.35	0											
(10.88)VI432	/r	Cnrv	twin				-0.073	-0.095	-0.121	-0.123	-0.123	-0.123	-0.123	-0.124	-0.124	-0.125	-0.126
"	/r	Cnrv			CL = .25		-0.121	-0.121	-0.121	-0.122	-0.122	-0.123	-0.123	-0.124	-0.125	-0.126	-0.127
"	/r	Cnrv			CL = .75		-0.122	-0.123	-0.123	-0.123	-0.124	-0.124	-0.125	-0.126	-0.127	-0.127	-0.128
(10.87)VI432	/r	Cnrw					-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002
"	/r	Cnrw			CL = .25		-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002
"	/r	Cnrw			CL = .75		-0.003	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002
(10.44)VI398	/r	CnTB															
T2.2(I)14	#/hp/hr	cp(cruise,loiter)		0.6	0.53												
(10.7)VI374		CTx1					-5.222	2.1572	0.1574	0.0588	0.0366	0.0291	0.0259	0.0243	0.0234	0.0229	0.0227
(10.8)VI374		CTx1					6.8970	0.4524	0.1080	0.0502	0.0344	0.0287	0.0263	0.0252	0.0245	0.0242	0.0240
(10.14)VI377		CTxu					15.668	-6.471	-0.472	-0.176	-0.110	-0.087	-0.077	-0.073	-0.070	-0.068	-0.068
(10.27,26,25)VI383	/r	CyBf,CyBw,CyB		-0.051	0		-0.587	-0.588	-0.589	-0.591	-0.593	-0.595	-0.598	-0.602	-0.605	-0.609	-0.614
F10.17VI390		CyBv(wfh)/CyBveff			0.8930												
(10.32)VI389	/r	CyBv	twin				-0.536	-0.536	-0.538	-0.539	-0.541	-0.544	-0.547	-0.550	-0.554	-0.558	-0.562
(10.28)VI386	/r	CyBv	single			-0.265	-0.268	-0.268	-0.269	-0.269	-0.270	-0.272	-0.273	-0.275	-0.277	-0.279	-0.281
F10.18VI391	/r	CyBveff		inter	2.0682	2.0083	2.1082										
(10.105)VI442	/r	CYda			0												
10.123)VI461	/r	CYdr					0.3383	0.3388	0.3395	0.3406	0.3419	0.3435	0.3454	0.3475	0.3499	0.3524	0.3552
(10.50)VI417	/r	Cyp					0.2290	0.1712	0.0458	-0.000	-0.022	-0.034	-0.041	-0.046	-0.049	-0.051	-0.052
"	/r	Cyp			CL = .25		-0.040	-0.040	-0.040	-0.040	-0.041	-0.041	-0.041	-0.041	-0.041	-0.042	-0.042
"	/r	Cyp			CL = .75		-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
(10.80)VI428	/r	Cyr					-0.281	0.3205	0.3613	0.3653	0.3661	0.3669	0.3682	0.3699	0.3720	0.3745	0.3773
VII44	#	D(rag)			2158.1												
F10.3VI375		dCD/dM					-128.8	-67.88	-4.022	-0.736	-0.214	-0.080	-0.035	-0.017	-0.009	-0.005	-0.003
(8.81)VI324		dCm/dCL		Xcg(fwrd)			-0.093	-0.092	-0.090	-0.087	-0.083	-0.079	-0.073	-0.066	-0.057	-0.047	-0.035
"		dCm/dCL		Xcg(aft)			-0.003	-0.002	-0.000	0.0023	0.0061	0.0108	0.0167	0.0238	0.0321	0.0424	0.0549
(8.109)VI342		(dCN/da)pi															
(5.46)one265	r	dde/dCL	must be neg.				-0.195	-0.191	-0.186	-0.178	-0.167	-0.155	-0.140	-0.122	-0.103	-0.082	-0.057
(5.106)one295	r	ddedn	must be neg.				-167.1	-82.93	-55.10	-41.22	-32.89	-27.34	-23.36	-20.37	-18.04	-16.16	-14.61
VI346,230,447	d,r	d(elev,flap,aile)		30	0.5235	40	0.6981	30	0.5235	daleft=	30	darigh=	-30	<<--T.E.down is +			
(8.45)VI272		de/da				0.3516	0.3523	0.3544	0.3579	0.3630	0.3696	0.3782	0.3887	0.4017	0.4173	0.4363	0.4593
"	hh=0	de/da				0.4152	0.4160	0.4185	0.4226	0.4286	0.4365	0.4466	0.4590	0.4743	0.4928	0.5152	0.5423

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
F8.115VI327		de[-]/da			3.0244												
F8.115VI327	cu(1)	(de[-]/da)i=1			1.1172	1.1172											
		"2			1.1700	1.1700											
		"3			1.2593	1.2593											
		"4			1.4095	1.4095											
	cu(2)	"5			3.0244												
(8.87)VI326		(de[-]/da)i=6				0.2804	0.2800	0.2788	0.2768	0.2740	0.2702	0.2654	0.2594	0.2520	0.2432	0.2324	0.2194
		"7				0.0934	0.0933	0.0929	0.0922	0.0913	0.0900	0.0884	0.0864	0.0840	0.0810	0.0774	0.0731
		"8				0.0117	0.0117	0.0117	0.0116	0.0114	0.0113	0.0111	0.0108	0.0105	0.0102	0.0097	0.0092
		"9				0.0353	0.0352	0.0351	0.0348	0.0344	0.0340	0.0334	0.0326	0.0317	0.0306	0.0292	0.0276
		"10				0.0588	0.0587	0.0585	0.0580	0.0574	0.0566	0.0556	0.0544	0.0528	0.0510	0.0487	0.0460
		"11				0.0823	0.0822	0.0819	0.0813	0.0804	0.0793	0.0779	0.0761	0.0740	0.0714	0.0682	0.0644
		"12				0.1059	0.1057	0.1053	0.1045	0.1034	0.1020	0.1002	0.0979	0.0952	0.0918	0.0877	0.0828
		"13				0.1294	0.1292	0.1287	0.1278	0.1264	0.1247	0.1225	0.1197	0.1163	0.1122	0.1073	0.1013
F12.5II286	ft	Def,Deg,Dg,Dhl,Dn		1.5	1.026	1.1	1.5	1.8									
F10.9VI384	in,ft	Df		60	5												
(10.36)VI397	ft	dfave			4.6172												
T5.1V82		Dgm,Dgn	0	0													
(8.86)VI326		dM/da				0	75.853	305.00	692.33	1246.2	1979.0	2907.6	4054.7	5449.8	7131.2	9148.7	11566.
V90	ft	Dp	8.18														
(10.31)VI389		(1+dsigma/dB)nv			1.0714												
F8.126VI338	in,ft	dt		9	0.75												
V95	#/s	(dWF/dt)TO	1.2														
VI377		dX[-]acA/dM				11.206	-0.023	-0.039	-0.056	-0.074	-0.094	-0.117	-0.142	-0.165	-0.207	-0.249	-0.292
(5.45)VII142	hr	E			16.816												
(4.12)VI27		e	incomplete				0.8318	0.8332	0.8356	0.8389	0.8433	0.8487	0.8551	0.8627	0.8713	0.8812	0.8923
VI69		eh	0.75														
T7.1IV322	VA	Electic		1000													
VI271	d	eoh	0														
F5.22VI131	sqf	f	21														
F2.22IV31	in	F			271												
VII134		fmp	326														
T5.1VII119		fTO	1														
(5.2)IV287	#/hr	Fuel flow max			6360												
IV287	#/hr	Fuel pump max flow			9540												

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
Overall	in	F.S.c.g.	aft	409.49	forw	397.61	case	397.61									
Operating	in	F.S.c.g.	aft	409.49	forw	397.61	case	397.61									
Water line	in	W.L.c.g.	low	83.548	high	95.095	case	83.548									
Leading edge	in	F.S.L.E.mgc		336													
Gravity	ft/s2	g	32.174														
F10.7VI382	d,r	gamma			dihedra	0	0										
VII162		gamma[-]	0.1														
(5.11)VII121		gammaLOF			0.2451												
F10.28VI399	ft	h		6.9166													
Ceilings			abso	servi	combat	cruise											
(5.21)VII127	ft	h	45757.	43180.	30291.	37331.											
F10.28VI399	ft	h1,h2,(h1/h2)^.5		6.92	5	1.1764											
VII135	ft	hcl	5000														
V76	in,ft	hf		86	7.1666												
V77,75	in,ft	hf boom		60	5												
F8.66VI274	ft	hh		11													
VII164	ft	hL	50														
T5.1VII119	ft	hT0	50														
F10.28VI399	ft	h/Wf		1.0641													
V91		int	0														
(6.140)one442	slug.sqf	Ixxs					65136.	55695.	42469.	41286.	41418.	41670.	41883.	42046.	42169.	42232.	42255.
"		Izzs					79323.	88764.	101990	103173	103041	102789	102576	102413	102290	102227	102204
"		Ixzs					30127.	-26165	-8501.	-714.5	2937.6	4908.7	6089.2	6852.0	7373.9	7624.5	7716.5
(3.12)VI20		K			0.0478												
(10.54)VI419		k(wing)				0.8662	0.8673	0.8706	0.8762	0.8841	0.8947	0.9081	0.9247	0.9452	0.9700	1.0003	1.0372
F8.13VI228		k'		0.62													
F(8.111)VI319		k2-k1			0.9263												
F10.47VI448		Ka		-0.105													
(11.5)II264		ka					0.6770	0.6774	0.6780	0.6790	0.6803	0.6819	0.6840	0.6866	0.6899	0.6940	0.6992
(8.46)VI272		KA			0.0966												
V272		KA*Klambda*Kh			0.1201												
VI272	hh=0	KA*Klambda*Kh			0.1381												
(7.31,32)V105		Kapi	887	212													
F8.52VI260		Kb(rudder)		0.5													
V95,110,108,87,93		Kb,Kbc,Kbuf,Kd,Kec(n-a,after)				1.3	0.316	1.02	1	0.686	1.08						
F10.22VI394		Kf(wing,H.tail)		0.94	0.81												
V77 press,main,cargo		Kf	1.08	1.07	1.1												

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
V99,100		Kfc,Kfcf	0.64	138													
V91	\$/gal	Kfsp	6.55														
V75,82		Kf(tailboom),Kgr		1	1												
(8.48)VI272		Kh,Kh(hh=0)		0.9406	1.0817												
V74		Kh	1														
(10.54)VI419		k(h.tail)				0.9688	0.9700	0.9737	0.9799	0.9888	1.0006	1.0156	1.0343	1.0571	1.0849	1.1187	1.1601
F10.8VI384		Ki			1.1666												
V77		Kinl	buried	1.25	1	else											
(8.47)VI272		Klambda			1.3214												
V108,87		Klav,Km	0.31	1													
F10.25VI396		KMgamma(wing)					1	1.01	1.015	1.02	1.025	1.028	1.03	1.05	1.07	1.085	1.1
"		KMgamma(H.tail)					1	1	1	1.01	1.015	1.02	1.025	1.03	1.04	1.055	1.07
F10.21VI394		KMlambda(wing)				1	1	1	1.005	1.01	1.02	1.03	1.045	1.07	1.09	1.12	1.15
"		Kmlambda(H.tail)					1	1	1	1	1	1.01	1.02	1.025	1.04	1.05	1.07
F10.28VI399		KN		0.0024													
V78	\$/hp	Kn	0.37	0.24	radi,hori												
V96,84		Kosc,Kp	0.07	0.45													
(10.54)VI419		kP				1	1.0012	1.0050	1.0114	1.0206	1.0327	1.0482	1.0675	1.0910	1.1197	1.1547	1.1973
(6.4,6)V84		Kpg	1.4														
V89,90		Kprop1,2	24	0.108													
F10.29VIp400		KRl					1.62	1.7	1.8	1.84	1.9	1.92	1.94	1.987	2.033	2.08	2.095
V109	\$	Kst	100														
V85		Kthr	1														
F10.12VI385		kv		0.9907		0.9907	0	0									
V74,71		Kv,KW	1	1													
(5.21)V74		Kv			1.1774												
(10.54)VI419		kv				0.9688	0.9700	0.9737	0.9799	0.9888	1.0006	1.0156	1.0343	1.0571	1.0849	1.1187	1.1601
F10.16VI390		Kvh			1.0157												
F10.40VI427		Kw		0.8027	conditi	0.8027	0.8027										
(8.44)VI272		Kwf			1.0006												
F2.22IV31	in	L	tricy.config.		238.61												
F4.4VI26		L'	1.2														
F12.5II286	ft	l1		2.5													
VII119		lambda	1														
(10.106)VI446	d	LAMBDA B(wing)				12.5	12.515	12.560	12.638	12.749	12.896	13.083	13.314	13.598	13.941	14.358	14.866
"	d	LAMBDA B(h.tail)					0	0	0	0	0	0	0	0	0	0	0
Fus.finess.rat.		lambda f			8.9166												

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
F4.2VI24	d	lambda(t/c)max		8.5													
F4.2VI24		cos(lambda(t/c)max)			0.9890												
V87	in,ft	Ld		20	1.6666												
VII133		L/D					1.6721	6.3915	12.061	14.949	14.255	12.014	9.7168	7.8221	6.3544	5.2312	4.3664
VII133		(L/D)cr(uise),(L/D)cr1			10.841	ERR											
VII133		(L/D)max			14.949												
(3.10)VI20		(L/D)max			14.882												
Fusel. length	in,ft,	lf,lf/b,lf/bh		535	44.583	0.5283	1.5462										
VI319		lf/df			8.9166												
V76		lf-n		480	40												
F10.28VI399		l[2]f/SBs			9.3683												
Gas gen lengt	ft	lg		0.3													
VI274,V77	in,ft	lh		400	33.333												
F2.14IV19	in	lm		20.51													
F12.5II286	ft	ln	Vp80	2													
V105	ft	lpax	0														
V81	in,ft	lsm,lsn		72	6	72	6										
F2.14IV19	in	lt		-238.6													
F10.27VI396	in,ft	lv(to case c.g)		339.38	28.282	Same as xv in F11.4IIp266											
V74	in,ft	lv(to c[-]/4)		365	30.416												
VI144	#	Lwf			19345.												
one413	slugs	m			1227.9												
Mach		M				0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
F2.22IV31	in	M	tricycle confi		20.51												
		Mcos(lambda c/4)				0	0.0488	0.0976	0.1464	0.1952	0.2440	0.2928	0.3417	0.3905	0.4393	0.4881	0.5369
VI394		Mcos(lambda c/2)				0	0.0494	0.0989	0.1483	0.1978	0.2472	0.2967	0.3461	0.3956	0.4450	0.4945	0.5439
F2.2I10		Mcr			0.3634												
V104		MD			0.4808												
(2.13)I16,V69		Mff,MH			0.8500	0.5292											
Load factor		n	1														
F2.22IV31	in	N	tricycle confi		250.49												
VII164		^n	0.1														
F8.97VI303	in,ft	na.c.		96	8	7.5833											
V94,90		Nbl	6	blades													
V108,109		Ncc,Ncr	0	1													
V103,108		Ne,Nfdc	2	0													
T2.18IV54		ng	4														

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
Fire retardant	US gal	Ngal	2000														
(8.41)VI271		nh.tail	prop				1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
"		npylon					1	1	1	1	1	1	1	1	1	1	1
VI442		ni,no(aile)		0.548	0.982												
V87,80		Ninl	2														
T4.1V39		nlimt,-	7.33	-3													
F8.97VI303	in,ft	nmgc		58	4.8333	Used if A>5											
V90,103		Np,Npax	2	prop(s)	1	incl.crew(s)											
T2.2I14		np(cr,ltr)	0.86	0.8													
V103,108		Npil,Nrow	1	0													
F2.22IV31		ns	2														
T2.17IV54		ns,nt	0.8	0.47													
V91,109		Nt,Ntroop	4	0													
V70,81		nult,nult.1		10.995	5.7												
V80	psi	P2	30	30													
V109	psi	Pc	12.23														
F10.18VI391	d	phi TE		12													
AIAA	hp	Pmax	12000														
Vp(ix),76	in,ft	pmax		240	20												
F2.22IV31	#	PMsmax,PNsmax		18258.	4721.6												
(5.8)VII119	hp	Preqd,cr			1379.2												
(5.66)VII153	hp	Preqd,maneu			20631.												
(5.61)VII152	r/s	psi[.]1				0.5536											
Jane's	hp	PTO	12000														
VII119,I102	hp/sqf	PTO/NDP^2			89.669												
(5.57,60)VII152	r/s	Q1	pullup	0.4826	0.5484	level turn											
(4.2)VI21	#/sqf	q[-]				0	3.7032	14.812	33.328	59.251	92.580	133.31	181.45	237.00	299.96	370.32	448.08
V61,78	psf	q[-]D,L			648.18												
one413	#	q[-]S					3295.8	13183.	29662.	52733.	82396.	118650	161497	210935	266964	329586	398799
Reynolds wing		R				0	4E+06	8E+06	1E+07	2E+07	2E+07	2E+07	3E+07	3E+07	4E+07	4E+07	4E+07
(5.34)VII134	n.m.	R			1190.7												
VII137	n.m.	R1	200														
F10.17VI390	ft,	2r1,2r1/bv		3	0.2903												
(5.21,23)VII126	fpm	RC		7773.1	6497.4												
Rates of climb			absolu	servi	combat	cruise											
T5.2VII129	fpm	RC	0	100	500	300											
(5.37)VII135	n.m.	Rcl			1.9297												

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
V104	n.m.	R(cr)	625														
T1.1red11	slug/ft3	rho	0.0023														
F4.1VI24		RNfus				0	2E+07	3E+07	5E+07	6E+07	8E+07	9E+07	1E+08	1E+08	1E+08	2E+08	2E+08
F4.2VI24		RLS	Regr			1.0679	1.0679	1.0679	1.0679	1.0679	1.0679	1.0793	1.0908	1.1023	1.1137	1.1252	1.1366
(5.62)VII153	ft	Rt			762.24												
F4.1VI24		Ruf			figure>	1.1	1.05	1	0.95	0.94	0.93	0.94	0.95	0.977	0.987	0.995	1.005
(5.82)VII162	ft	sAIR			1057.2												
F10.28VI399	sqf	SBs		212.16													
T58GE16JANES	#/h/shp	sfc	0.53														
V77,(77,75),110	sqf	Sfgs,Sfgs boom,Sff			500	300	0										
(5.80)VII162	ft	sFL			3619.4												
VII44	sqf	^Sflaps		42.86													
(2.39)VII44	sqf	Sh			145.55												
VI271	sqf	(Sh)slip		42.263													
		Sh/Sv			1.3333												
Density ratio		sigma			1												
(5.81)VII162	ft	sL			2171.6												
(5.88)VII164	ft	sLG			1114.4												
II264		^SM		-0.073													
VI383,385	sqf	So		19.6													
V99	sqf	Ssc	20														
(5.6,14)VII117,122	ft	sTO,sTOG			1350.9	1401.0											
	sqf	Swet.Fus.			670.08												
	sqf	Swetbooms			539.12												
(12.5)II285	sqf	Swet.Fan cowl/E			10.912												
"	sqf	SwetcowlTOT			ERR												
(12.6)II285	sqf	Swet.Gasgen/E			1.0499												
"	sqf	Swet.Gasgen.Total			ERR												
	sqf	Swet.Pylon		0													
nacel TOT	sqf	Swet.Nacelle			ERR												
	sqf	Swet GPU-5A			96.865												
	sqf	Swet 4(LAU-3)			90.757												
	sqf	Swet Wing fairing			18.472	Swet total with:											
	sqf	Swet intersections			14.943	GPU-5A	4(LAU-3)										
Tot wet area	sqf	SwetTOT			3428.4	3428.4	3428.4										
(5.4)VII113	#	T			33486.												
(5.28)VII131	#	T					-17213	28439.	4671.4	3102.7	3022.4	3457.6	4186.7	5132.8	6262.6	7575.3	9061.5

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
(5.7,8)VII119	#	T[-],T[-],T[-]ave		30137.	15415.	22776.											
(5.38)VII135	s,min	tcl		38.594	0.6432												
V68	652-415	(t/c)max	0.15														
(5.28)VII131	#	Tcruise			3644.2												
VII131	d,r	thetaT	0		0												
VII44	d/s^2	theta[.]	10														
V80	#	TTO			15415.												
VII123		(T[-]/W)TO			0.3901												
(5.31)VII133		(T/W)cr(uise)			0.0922												
T1.1red11	#s/sqf	u	4E-07	viscosity coef													
M x a	fps	U				0	55.82	111.64	167.46	223.28	279.1	334.92	390.74	446.56	502.38	558.2	614.02
	mph	U				0	38.058	76.116	114.17	152.23	190.29	228.34	266.40	304.46	342.52	380.58	418.63
(5.9)VII121		u'			0.0321												
Cruise,maneuv	kts,fps	U1	200	337.6	250	422											
VII40		ug	0.02														
(4.9)V33	kts,fps	VA	236.25		398.79												
(5.85)VII64	fps,kts	VA		189.35	112.17												
V108	cu.ft	Vcargo	0														
Cruise	kts,fps	Vcr(uise)	250		422												
VII135,V76	kts,fps	Vcl(imb)	180		303.84												
(4.21)V37	kts,fps	VD		312.5	527.5												
V38,68	kts,fps	VH	350	590.8													
(10.23)VI382		V[-]h			0.5126												
V38	kts,fps	VL		437.5	738.5												
VII141	kts,fps	Vltr	129.97		219.39												
VII122	kts,fps	VLOF	106.43		179.67												
(10.23)VI382		V[-]p			-0.000												
V102,108	cu.ft	Vpax,Vpax+carg		0	0												
V105	?	Vpr	0														
(5.3)VII113	kts	Vs			99.270												
(5.5)VII115	kts,fps	Vs		100.41	169.50	cruise											
(4.19)V35	kts,fps	Vsl		87.261	147.29												
(3.1)I90	kts,fps	VsL		93.482	157.79												
VII122	kts,fps	VsTO		96.763	163.33												
(5.87)VII164	fps,kts	VTD		179.64	106.42												
T5.1VII119		V3/VsTO	1.15														
(6.2)II153	cu.ft	VWF			638.71												

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
			W1/WTO	W2/W1	W3/W2	W11/W10	W12/W11										
T2.1I12		W(i+1)/Wi	0.992	0.99	0.996	0.99	0.99										
F2.2I10		W4/W3	0.9870	climb													
		W5/W4	0.8982	cruise													
Air induc.sys			(6.8)	(6.9)	(610)	(ave)											
V87,88	#	Wai(+Wp)	559.56	87.322	39.285	63.304											
Air-cond,press,anti-deic			(7.26)	(7.27)	(7.28)	(7.29)	(7.30)	(7.31)	(7.32)	(7.33)	(ave)						
V104	#	Wapi	178.92	2.5	205.09	0	0	0	180.37	161.98	171.17						
Acc,powr.contr,start,ign			(6.34a)	(6.34b)	(ave)												
V95	#	Wapsi	86.4	629.11													
(7.40)V107	%,#	Wapu	0.006		237.04												
(7.50)V111	#	Waux			205.09												
Bag.carg.handl.equip			(7.48)	(7.49)	(ave)												
V110	#	Wbc	0.316	0													
T2.16I48		Wcomp/Wmetal		0.85													
V59	#	Wcrew	400														
V104	#	WE	20509														
Engine			(6.2)	(6.7)	(ave)												
V84,85	#	We	5400	2200	2200												
(2.16)I18	#	WE<1,2>.>>	25176.	21400.													
Eng.cont			(6.23)n	(6.23)y	(6.24)	(6.25)	(6.26)	(ave)									
V93,94	#	Wec	24.037	37.842	116.87	92.504	119.68										
Elec,hydrau,pneu.sys			(7.12)	(7.13)	(7.14)	(7.15)	(7.16)	(7.17)	(7.18)	(7.19)	(7.20)	(ave)					
V101,102	#	Wels+Whps	1058.8	542.37	1165.2	1477.9	915.03	0	337.25	266.40	441.58	478.58					
Empennage			(5.11)	(5.16)	(ave)												
V71,73	#	Wemp	1141.3	1131.6													
VII142	#	Wend			29308												
AIAA	#	Weng+gearbox		1100	V84												
V14	#	Weng.inst.	30														
Eng.start.sys			(6.27)	(6.28)	(6.29)	(6.30)	(6.31)	(ave)									
V94	#	Wess	21.827	75.357	80.283	38.039	72.348										
(2.5)I7	#	WEtent			14812.												
(6.3)V84	#	We+Wai+Wprop+Wp			3280.7												
I7	#,%WTO	WE<2>-WEtent		6587.5	16.673	<= 5% ??											
(2.15)I16	#	WF		7407.6	7407.6	10200 given											
Fusel			(5.23)	(5.24)	(5.25)	(5.26)b	(5.26)e	(5.27)p	(5.27)m	(5.27)c	(5.28)b	(5.28)e	(ave)				
V75-77	#	Wf	6.2596	224.06	2279.4	2924.7	2130.5	1085.0	1484.4	1105.1	2568.2	1951.8	2384.2				

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
(5.27)V77,75	#	Wf(/tailboom)			599.86												
Flight cont.sys			(7.2)	(7.3)	(7.4)	(7.5)	(7.6)	(7.7)	(7.8)	(7.9)	(7.10)	(ave)					
V98-100	#	Wfc	804.04	1782.8	266.79	1366.1	742.39	1465.0	23.290	1168.2	1356.3	1006.4					
(7.11)V100	#	Wfccg			68.306												
(6.26)V92	#	Wfd			22.414												
(5.22)V75	#	Wffl.boat	mono	3934.0	1979.5	(2 floats)											
VI399,V76	in,ft	ufmax		78	6.5												
V77,75	in,ft	ufmax(tailboom)		75	6.25	IVp125(bf)											
I16	%	WFres	0.25	of WFused													
Fuel sys			(6.15)	(6.16)	(6.17)	(6.18)	(6.19)	(6.20)	(6.21)	(6.23)	(6.24)	(ave)					
V90-92	#	Wfs	452.37	791.65	639.80	234.11	326.46	365.33	208.02	530.88	711.82	1065.1					
(5.41)VII137	#	Wfuel1			680.01												
Furnish			(7.41)	(7.42)	(7.43)	(7.44)	(7.45)	(7.46)	(7.47)	(ave)							
V107-109	#	Wfur	72.891	18	15	103.03	2661.9	113.65	153.96								
(2.14)I16	#	WFused			5926.1												
Land.gear			(5.38)	(5.39)	(5.40)	(5.41)	(5.42)m	(5.42)n	(5.43)	(ave)							
V81,82	#	Wg	665.66	1218.7	586.35	1364.8	974.75	180.13	1461.2	1079.7							
H.tail			(5.12)	(5.14)	(5.17)	(5.19)	(ave)										
V71-74	#	Wh	1542.5	525.74	676.48	841.42	758.95										
V101	#	Whydrau			395.08												
(7.23)V103	#	Wi			506.76												
Instr,avio,electro			(7.21)	(7.22)	(7.24)	(7.25)	(ave)										
V103,104	#	Wiae	33	356.06	397.04	717.92	540.57										
VII142	#	Winitial			39508												
(6.25)V92	#	Winflref			214.66												
T3.3I107	%WTO,#	WL	0.95		37532.	Vp81											
(5.8)V69	#	WMZF			32100.												
Nacelle			(5.29)r	(5.29)h	(5.30)	(5.31)	(5.32)	(5.33)	(5.34)	(5.35)	(5.36)	(5.37)	(ave)				
V78-80	#	Wn	4440	2880	273.86	3840	5651.8	1680	169.68	420.54	847.87	1002.0					
(2.4)I7	#	WOEtent			15410.												
(6.38)V96	#	Wosc			77												
(7.51)V112	%WTO,#	Wpaint	0.3		118.52												
Prop.contr			(6.32)	(6.33)	(ave)												
V94,95	#	Wpc	205.44	291.74													
V59	#	WPL			16690	A2VIp521(specific weight factor)											
Prop			(given)	(6.13)	(6.14)	(ave)											
V89,90	#	Wprop	250	2031.3	2027.6	250											

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
VII123	#/hp	(W/P)climb			15												
VII126	#/hp	(W/P)TO			3.2923												
Powerplant			(6.1)	(6.4)	(6.6)	(ave)											
V83,85	#	Wpwr	3689.5	5572	7560												
(6.5)V85	#	Wsprch			1505.4												
VII123	psf	(W/S)TO			44.391	STO needs to be evaluated											
(6.22)V92	#	Wsupp			62.778												
IV4	fps	wt	17														
I7	%,#	Wtfo	0.5		197.54												
Take-off	#	WTO			39508												
(6.36)V95	#	Wtr			396												
V.tail			(5.13)	(5.15)	(5.18)	(5.20)f	(5.20)f	(ave)									
V71-74	#	Wv	91.868	197.24	416.51	348.34	410.15	382.43									
Wing			(5.2)	(5.3)	(5.4)	(5.5)	(5.6)	(5.7)	(5.9)	(5.10)	(ave)						
V60-70	#	Ww	3279.4	2184.2	6704.5	6065.3	3948.9	7133.0	6960.8	8203.1	7656.9						
2)V60	#	Ww+(due to complex flaps			696.08												
V96	#	Wwi,Wwtr			0	0											
(8.82)VI324		x[-]acA					0.5603	0.5591	0.5571	0.5543	0.5506	0.5458	0.5400	0.5328	0.5246	0.5142	0.5017
	ft	xacA					6.1633	6.1505	6.1289	6.0979	6.0569	6.0048	5.9404	5.8618	5.7709	5.6567	5.5195
	in	xacA					73.960	73.807	73.547	73.175	72.683	72.058	71.285	70.342	69.251	67.881	66.234
(11.1)II261	Sh/4	x[-]acA	40	Sh/i		F,X[-]a	1.0278	0.3316	1.0273	0.3302	1.0265	0.3279	1.0252	0.3243	1.0233	0.3195	1.0207
(11.2)II261	Sh/2	"	80				1.0557	0.4104	1.0547	0.4079	1.0530	0.4033	1.0504	0.3963	1.0467	0.3865	1.0414
	3Sh/4	"	120				1.0836	0.4853	1.0821	0.4815	1.0796	0.4750	1.0757	0.4649	1.0701	0.4505	1.0621
	Sh	"	160				1.1115	0.5563	1.1095	0.5516	1.1061	0.5432	1.1009	0.5303	1.0934	0.5118	1.0828
	5Sh/4	"	200				1.1394	0.6239	1.1369	0.6183	1.1327	0.6082	1.1262	0.5928	1.1168	0.5705	1.1035
	3Sh/2	"	240				1.1672	0.6883	1.1643	0.6818	1.1592	0.6703	1.1514	0.6526	1.1402	0.6269	1.1242
	7Sh/4	"	280				1.1951	0.7496	1.1917	0.7424	1.1858	0.7296	1.1767	0.7098	1.1636	0.6809	1.1449
	2Sh	"	320				1.2230	0.8082	1.2191	0.8003	1.2123	0.7862	1.2019	0.7645	1.1869	0.7328	1.1656
(8.85)VI326		^x[-]acf	fuselage				-0.029	-0.029	-0.029	-0.029	-0.029	-0.028	-0.028	-0.028	-0.028	-0.028	-0.028
		^x[-]acb	booms				-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	in,ft,	xach,x[-]ach,xacv,x[-]acv				438	36.5	3.3181	401	33.416	3.0378						
Pylons	ft,	xacp,x[-]acp		0.0000	0.0000												
F8.97VI303	in,ft,ft	xacw	37	3.0833	3.1666												
		x[-]acw			0.2803												
(8.83)VI324		x[-]acwf					0.2483	0.2483	0.2483	0.2484	0.2484	0.2485	0.2486	0.2487	0.2493	0.2494	0.2496
F10.44VI433		x[-]/c[-]					0.0035	0.0024	0.0004	-0.002	-0.006	-0.010	-0.016	-0.023	-0.032	-0.042	-0.054
F8.114VI323	ft,	xcg,x[-]cg(aft,forw,case)				6.1241	0.5567	5.1343	0.4667	5.1343	0.4667						

Table C.3 MACH NUMBER DEPENDENT PARAMETERS

Reference	Unit	Variable	Given	Measu	Compu	M=0	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55
F8.116VI327	ft,	xh		24.5													
F10.28VI399	ft,	xm,xm/lf		32.17	0.7215												
F2.5VII39	ft	x(m,n or t)g		7.8333	14.75												
F10.11VI385	ft	xo			39.048												
F8.91VI298		x[-]ref case			0.4667												
F11.4II266	in,ft	xv		339.38	28.282	Same as lv in F10.27VIp396											
F10.39VI426	ft	xw			-2.051												
F2.5VII39	ft	zD		0													
No237,170	ft	zf		5													
V73	in,ft	zh		110	9.1666	Def. in Table of symbols											
F2.5VII39	ft	zmg			7.5												
F2.5VII39	ft	zT		0.75													
F10.27VI396	ft	zv		4													
F10.9VI384	in,ft	zw(wing,H.tail)		10	0.8333	-110	-9.166										

Table C.4.1 LONGITUDINAL AND LATERAL-DIRECTIONAL DIMENSIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: TAKE-OFF AT SEALEVEL, WEIGHT = 39,508 LBS, M = 0.15

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			55.82	111.64	167.46	223.28	279.1	334.92	390.74	446.56	502.38	558.2	614.02	669.84
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			0.9571	1.6863	3.5675	6.3460	10.050	14.760	20.595	27.711	36.317	46.685	59.179	74.283
Pitch angle	d,r	theta1	0	0												
(B4)one538	sec	T2P			-13.55	3.8680	41.829	-599.3	-110.8	-76.83	-62.25	-53.29	-46.90	-41.99	-38.02	-34.77
(6.141)one446		A1	(Ixz/Ixx)s		0.4625	-0.469	-0.200	-0.017	0.0709	0.1178	0.1453	0.1629	0.1748	0.1805	0.1826	0.1831
"		B1	(Ixz/Izz)s		0.3798	-0.294	-0.083	-0.006	0.0285	0.0477	0.0593	0.0669	0.0720	0.0745	0.0755	0.0757
T6.8one445	/s2	LB			-1.519	-0.838	-2.447	-4.584	-7.250	-10.47	-14.30	-18.78	-23.87	-29.37	-35.23	-41.54
"	/s2	LdA			0.9400	4.4310	13.242	24.657	39.326	57.988	81.435	110.68	147.11	192.84	250.76	325.18
"	/s2	LdR			-0.308	-1.079	-0.852	0.0183	1.1758	2.5853	4.2536	6.1915	8.4100	10.767	13.268	15.962
"	/s	Lp			-4.566	-3.364	-5.941	-8.182	-10.53	-13.14	-15.64	-18.47	-21.70	-25.62	-30.47	-36.64
"	/s	Lr			8.4010	5.0555	5.4657	5.4090	5.5399	5.8325	6.2310	6.7005	7.2210	7.7513	8.2881	8.8377
T6.3one413	/s2	Ma			-0.163	-0.650	-1.445	-2.522	-3.837	-5.325	-6.884	-8.363	-9.593	-10.12	-9.463	-6.914
"	/s	Ma[.]			-0.150	-0.303	-0.463	-0.634	-0.819	-1.025	-1.257	-1.524	-1.836	-2.209	-2.660	-3.217
"	/s2	MdE			-0.189	-0.761	-1.727	-3.107	-4.928	-7.230	-10.06	-13.49	-17.60	-22.50	-28.32	-35.22
"	/s	Mq			-0.469	-0.943	-1.426	-1.923	-2.439	-2.981	-3.555	-4.168	-4.831	-5.554	-6.351	-7.236
"	/s2	MTa														
"	/ft/s	MTu			0.0073	-0.006	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0012	0.0006	0.0001	-0.000	-0.000	-0.000	-0.001	-0.001	-0.002	-0.002	-0.002	-0.003
T6.8one445	/s2	NB			-0.593	1.6336	3.6562	6.4815	10.094	14.577	19.920	26.064	33.079	40.980	49.973	59.960
"	/s2	NdA			-0.821	-0.743	-0.659	-0.671	-0.697	-0.732	-0.777	-0.833	-0.905	-0.981	-1.064	-1.161
"	/s2	NdR			0.3115	-1.267	-2.798	-4.972	-7.796	-11.27	-15.43	-20.28	-25.85	-32.15	-39.20	-47.03
"	/s	Np			0.1234	-0.393	-0.242	-0.112	0.0357	0.2128	0.4229	0.6667	0.9436	1.2460	1.5718	1.9194
"	/s	Nr			-0.204	-0.465	-0.764	-1.024	-1.282	-1.542	-1.805	-2.073	-2.347	-2.624	-2.909	-3.199
"	/s2	NTB														
(6..173)one458	s	TR			0.2190	0.2972	0.1683	0.1222	0.0949	0.0760	0.0639	0.0541	0.0460	0.0390	0.0328	0.0272
(3.24)VI188		LBNr-NBLr>0			yes	no	no	no	no	no	no	no	no	no	no	no
(3.25)VI189	s	T2S			0.2347	-0.141	-0.121	-0.107	-0.097	-0.088	-0.080	-0.074	-0.068	-0.063	-0.058	-0.053
(6.161)one454	s	TS			0.3386	-0.204	-0.175	-0.154	-0.140	-0.127	-0.116	-0.107	-0.098	-0.091	-0.083	-0.076
(3.26)VI189	r/s	WnD			ERR	1.2810	1.9165	2.5518	3.1848	3.8272	4.4740	5.1180	5.7661	6.4181	7.0875	7.7636

Table C.4.1 LONGITUDINAL AND LATERAL-DIRECTIONAL DIMENSIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: TAKE-OFF AT SEALEVEL, WEIGHT = 39,508 LBS, M = 0.15

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			ERR	0.2611	0.4248	0.5692	0.7126	0.8570	1.0032	1.1527	1.3046	1.4587	1.6169	1.7781
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0487	0.0489	0.0492	0.0496	0.0502	0.0509	0.0518	0.0529	0.0542	0.0558	0.0577	0.0601
(3.11)VII78	r/s	Wn S.P.			0.6501	1.0530	1.5566	2.0690	2.5814	3.0907	3.5934	4.0849	4.5641	5.0070	5.3998	5.7214
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-1.830	-1.847	-1.875	-1.917	-1.972	-2.043	-2.132	-2.242	-2.373	-2.502	-2.621	-2.735
"	/s	XTu			0.2511	-0.207	-0.022	-0.011	-0.008	-0.008	-0.008	-0.009	-0.010	-0.011	-0.012	-0.013
"	/s	Xu			-0.353	0.5658	0.0558	0.0090	-0.003	-0.009	-0.013	-0.016	-0.019	-0.021	-0.024	-0.026
"	/s	X[-]u			-0.102	0.3584	0.0331	-0.002	-0.012	-0.018	-0.022	-0.026	-0.029	-0.033	-0.036	-0.039
T6.8one445	ft/s2	YB			-1.576	-6.315	-14.23	-25.38	-39.80	-57.56	-78.73	-103.4	-131.7	-163.6	-199.4	-239.1
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			0.9082	3.6377	8.2031	14.628	22.945	33.197	45.432	59.705	76.077	94.609	115.36	138.38
"	ft/s	Yp			0.4646	0.6947	0.2788	-0.004	-0.225	-0.415	-0.588	-0.752	-0.910	-1.051	-1.178	-1.299
"	"	Yr			-0.571	1.3007	2.1992	2.9649	3.7137	4.4665	5.2289	6.0038	6.7924	7.5980	8.4206	9.2591
T6.3one413	ft/s2	Za			-30.79	-54.25	-114.7	-204.1	-323.3	-474.9	-662.6	-891.5	-1168.	-1502.	-1904.	-2389.
"	ft/s	Za[.]			-0.381	-0.771	-1.178	-1.611	-2.082	-2.605	-3.195	-3.873	-4.667	-5.613	-6.759	-8.174
"	ft/s2	ZdE			-0.466	-1.873	-4.251	-7.645	-12.12	-17.79	-24.76	-33.20	-43.32	-55.37	-69.69	-86.67
(3.27)VII89		Zeta D			ERR	0.2038	0.2216	0.2230	0.2237	0.2239	0.2242	0.2252	0.2262	0.2272	0.2281	0.2290
(3.10)VII78		Zeta P	(6.113)one430		1.0479	-3.659	-0.336	0.0232	0.1244	0.1770	0.2147	0.2456	0.2723	0.2956	0.3155	0.3315
(3.12)VII78		Zeta S.P.			0.9007	0.8227	0.8272	0.8390	0.8556	0.8775	0.9055	0.9412	0.9853	1.0440	1.1215	1.2253
T6.3one413	ft/s	Zq			-1.266	-2.543	-3.845	-5.183	-6.571	-8.025	-9.563	-11.20	-12.97	-14.90	-17.01	-19.36
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.021	-0.027	-0.032	-0.038	-0.045	-0.054	-0.063	-0.075

Table C.4.2 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITIONS: CRUISE #1 (M = 0.40) AND LOITER (M = 0.25) FOR [W = 39,508 #, h = 5,000 ft]

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			54.855	109.71	164.56	219.42	274.27	329.13	383.98	438.84	493.69	548.55	603.40	658.26
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			1.0083	1.4561	2.9920	5.2936	8.3711	12.288	17.141	23.062	30.221	38.848	49.244	61.812
Pitch angle	d,r	theta1	0	0												
(B4)one538	sec	T2P			-87.50	-1.406	33.152	717.04	-153.2	-95.41	-75.16	-63.64	-55.74	-49.77	-45.00	-41.11
(6.141)one446		A1	(Ixz/Ixx)s		0.2029	-0.468	-0.272	-0.065	0.0408	0.0978	0.1314	0.1527	0.1672	0.1746	0.1779	0.1794
"		B1	(Ixz/Izz)s		0.0846	-0.363	-0.117	-0.026	0.0163	0.0395	0.0534	0.0625	0.0687	0.0719	0.0734	0.0741
T6.8one445	/s2	LB			-2.911	-0.657	-1.976	-3.801	-6.056	-8.767	-11.98	-15.73	-20.00	-24.61	-29.52	-34.80
"	/s2	LdA			1.1987	3.2564	10.720	20.462	32.797	48.395	67.947	92.311	122.64	160.71	208.91	270.85
"	/s2	LdR			-0.095	-0.980	-1.003	-0.316	0.6533	1.8382	3.2382	4.8621	6.7193	8.6921	10.783	13.037
"	/s	Lp			-7.854	-2.679	-4.965	-6.941	-8.956	-11.17	-13.28	-15.68	-18.41	-21.73	-25.83	-31.05
"	/s	Lr			12.782	4.4351	5.0924	5.0356	5.0816	5.2740	5.5698	5.9362	6.3535	6.7849	7.2263	7.6824
T6.3one413	/s2	Ma			-0.136	-0.541	-1.202	-2.098	-3.193	-4.431	-5.728	-6.958	-7.982	-8.422	-7.874	-5.753
"	/s	Ma[.]			-0.127	-0.257	-0.392	-0.537	-0.694	-0.868	-1.064	-1.290	-1.555	-1.870	-2.252	-2.724
"	/s2	MdE			-0.157	-0.633	-1.437	-2.585	-4.101	-6.016	-8.374	-11.22	-14.65	-18.72	-23.56	-29.31
"	/s	Mq			-0.397	-0.798	-1.207	-1.628	-2.065	-2.524	-3.010	-3.529	-4.091	-4.703	-5.377	-6.127
"	/s2	MTa														
"	/ft/s	MTu			0.0121	-0.048	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0013	0.0007	0.0004	0.0000	-0.000	-0.000	-0.000	-0.001	-0.001	-0.001	-0.002	-0.002
T6.8one445	/s2	NB			-0.471	1.3390	3.0443	5.3959	8.4025	12.132	16.578	21.691	27.529	34.103	41.586	49.896
"	/s2	NdA			-0.639	-0.809	-0.666	-0.669	-0.692	-0.725	-0.767	-0.820	-0.886	-0.958	-1.038	-1.134
"	/s2	NdR			0.2569	-1.060	-2.334	-4.140	-6.487	-9.385	-12.84	-16.88	-21.51	-26.75	-32.62	-39.13
"	/s	Np			0.0152	-0.389	-0.242	-0.122	0.0085	0.1622	0.3428	0.5513	0.7874	1.0448	1.3219	1.6173
"	/s	Nr			-0.214	-0.366	-0.643	-0.867	-1.087	-1.307	-1.529	-1.757	-1.988	-2.223	-2.464	-2.709
"	/s2	NTB														
(6.173)one458	s	TR			0.1273	0.3732	0.2014	0.1440	0.1116	0.0895	0.0752	0.0637	0.0543	0.0460	0.0387	0.0321
(3.24)VII88		LBNr-NBLr>0			yes	no	no	ho	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			0.3131	-0.156	-0.136	-0.120	-0.109	-0.100	-0.091	-0.085	-0.079	-0.073	-0.067	-0.062
(6.161)one454	s	TS			0.4517	-0.225	-0.197	-0.173	-0.158	-0.144	-0.132	-0.122	-0.113	-0.105	-0.097	-0.089
(3.26)VII89	r/s	WnD			ERR	1.1594	1.7482	2.3276	2.9047	3.4904	4.0802	4.6674	5.2582	5.8527	6.4631	7.0796

Table C.4.2 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITIONS: CRUISE #1 (M = 0.40) AND LOITER (M = 0.25) FOR [W = 39,508 #, h = 5,000 ft]

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			ERR	0.2073	0.3577	0.4820	0.6040	0.7264	0.8502	0.9767	1.1053	1.2357	1.3696	1.5061
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0496	0.0498	0.0501	0.0505	0.0511	0.0518	0.0527	0.0538	0.0552	0.0568	0.0587	0.0611
(3.11)VII78	r/s	Wn S.P.			0.6093	0.9392	1.3817	1.8337	2.2851	2.7319	3.1704	3.5954	4.0050	4.3749	4.6899	4.9260
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-1.829	-1.845	-1.871	-1.909	-1.960	-2.025	-2.107	-2.207	-2.326	-2.446	-2.560	-2.671
"	/s	XTu			0.4154	-1.679	-0.029	-0.012	-0.008	-0.007	-0.007	-0.008	-0.008	-0.009	-0.010	-0.011
"	/s	Xu			-0.431	0.6937	0.0708	0.0144	-0.000	-0.006	-0.010	-0.013	-0.016	-0.018	-0.020	-0.022
"	/s	X[-]u			-0.015	-0.985	0.0418	0.0019	-0.009	-0.014	-0.018	-0.021	-0.024	-0.027	-0.030	-0.033
T6.8one445	ft/s2	YB			-1.312	-5.254	-11.84	-21.12	-33.11	-47.89	-65.51	-86.05	-109.5	-136.2	-165.9	-198.9
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			0.7557	3.0269	6.8257	12.172	19.093	27.623	37.804	49.680	63.303	78.724	95.992	115.15
"	ft/s	Yp			0.0957	0.7275	0.3434	0.0769	-0.127	-0.299	-0.454	-0.599	-0.739	-0.862	-0.973	-1.078
"	"	Yr			-0.616	1.0147	1.8454	2.5093	3.1478	3.7864	4.4322	5.0881	5.7556	6.4373	7.1334	7.8429
T6.3one413	ft/s2	Za			-32.44	-46.84	-96.26	-170.3	-269.3	-395.3	-551.5	-741.9	-972.3	-1249.	-1584.	-1988.
"	ft/s	Za[.]			-0.323	-0.653	-0.997	-1.364	-1.763	-2.205	-2.705	-3.279	-3.951	-4.752	-5.723	-6.921
"	ft/s2	ZdE			-0.387	-1.559	-3.537	-6.361	-10.09	-14.80	-20.60	-27.63	-36.04	-46.07	-57.99	-72.12
(3.27)VII89		Zeta D			ERR	0.1788	0.2046	0.2071	0.2079	0.2081	0.2083	0.2092	0.2102	0.2111	0.2119	0.2127
(3.10)VII78		Zeta P	(6.113)one430		0.1595	9.8915	-0.417	-0.019	0.0884	0.1400	0.1747	0.2021	0.2252	0.2450	0.2619	0.2755
(3.12)VII78		Zeta S.P.			0.9157	0.7892	0.7907	0.8021	0.8187	0.8407	0.8691	0.9055	0.9508	1.0117	1.0934	1.2051
T6.3one413	ft/s	Zq			-1.072	-2.153	-3.256	-4.388	-5.564	-6.795	-8.097	-9.487	-10.98	-12.61	-14.41	-16.40
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.022	-0.027	-0.033	-0.039	-0.046	-0.055	-0.064	-0.076

Table C.4.3 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: CRUISE #2 (M = 0.4, W = 20,932 #, h = 5,000 ft

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			54.855	109.71	164.56	219.42	274.27	329.13	383.98	438.84	493.69	548.55	603.40	658.26
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			0.9677	2.5148	5.5438	9.9335	15.763	23.168	32.335	43.514	57.031	73.316	92.939	116.66
Pitch angle	d,r	thetal	0	0												
(B4)one538	sec	T2P			-62.44	4.5551	102.47	-98.71	-57.85	-45.13	-37.88	-32.88	-29.12	-26.16	-23.73	-21.73
(6.141)one446		A1	(Ixz/Ixx)s		-0.005	-0.482	-0.149	0.0084	0.0821	0.1215	0.1450	0.1601	0.1703	0.1739	0.1737	0.1722
"		B1	(Ixz/Izz)s		-0.016	-0.204	-0.051	0.0028	0.0277	0.0413	0.0495	0.0548	0.0585	0.0598	0.0597	0.0592
T6.8one445	/s2	LB			-0.260	-0.864	-2.292	-4.152	-6.506	-9.375	-12.79	-16.78	-21.32	-26.23	-31.47	-37.11
"	/s2	LdA			0.4475	4.5312	12.067	22.097	35.235	52.054	73.234	99.678	132.63	174.00	226.40	293.72
"	/s2	LdR			-0.226	-0.564	-0.108	0.6846	1.7056	2.9538	4.4374	6.1650	8.1456	10.255	12.495	14.911
"	/s	Lp			-1.247	-3.196	-5.403	-7.416	-9.581	-11.99	-14.30	-16.92	-19.90	-23.52	-27.99	-33.67
"	/s	Lr			2.5823	3.7023	3.8878	4.0243	4.3107	4.6973	5.1469	5.6389	6.1617	6.6823	7.1998	7.7217
T6.3one413	/s2	Ma			-0.040	-0.155	-0.323	-0.503	-0.633	-0.620	-0.329	0.4373	1.9097	4.6135	9.1374	16.316
"	/s	Ma[.]			-0.145	-0.293	-0.449	-0.614	-0.793	-0.992	-1.217	-1.476	-1.778	-2.139	-2.575	-3.115
"	/s2	MdE			-0.180	-0.724	-1.643	-2.956	-4.689	-6.879	-9.576	-12.84	-16.75	-21.41	-26.94	-33.51
"	/s	Mq			-0.448	-0.900	-1.361	-1.836	-2.329	-2.846	-3.393	-3.979	-4.611	-5.301	-6.060	-6.904
"	/s2	MTa														
"	/ft/s	MTu			0.0037	-0.001	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0007	0.0001	-0.000	-0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003	-0.003	-0.004
T6.8one445	/s2	NB			-0.100	1.2253	2.6733	4.7182	7.3342	10.581	14.453	18.903	23.982	29.705	36.226	43.468
"	/s2	NdA			-0.901	-0.328	-0.316	-0.326	-0.341	-0.361	-0.387	-0.420	-0.462	-0.505	-0.549	-0.599
"	/s2	NdR			-0.045	-0.937	-2.054	-3.643	-5.703	-8.244	-11.27	-14.81	-18.87	-23.47	-28.62	-34.33
"	/s	Np			-0.166	-0.203	-0.120	-0.037	0.0649	0.1933	0.3487	0.5309	0.7390	0.9673	1.2141	1.4779
"	/s	Nr			-0.016	-0.373	-0.560	-0.742	-0.927	-1.114	-1.304	-1.498	-1.695	-1.896	-2.102	-2.312
"	/s2	NTB														
(6.173)one458	s	TR			0.8015	0.3128	0.1850	0.1348	0.1043	0.0833	0.0698	0.0590	0.0502	0.0425	0.0357	0.0296
(3.24)VII88		LBNr-NBLr>0			yes	no	no	no	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			0.6835	-0.239	-0.204	-0.179	-0.159	-0.142	-0.128	-0.117	-0.107	-0.098	-0.089	-0.082
(6.161)one454	s	TS			0.9861	-0.345	-0.295	-0.258	-0.230	-0.206	-0.185	-0.168	-0.154	-0.141	-0.129	-0.118
(3.26)VII89	r/s	WnD			ERR	1.1109	1.6412	2.1804	2.7187	3.2657	3.8167	4.3653	4.9174	5.4731	6.0441	6.6210

Table C.4.3 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: CRUISE #2 (M = 0.4, W = 20,932 #, h = 5,000 ft

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			ERR	0.2318	0.3484	0.4623	0.5776	0.6945	0.8130	0.9342	1.0573	1.1824	1.3108	1.4416
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0496	0.0498	0.0501	0.0505	0.0511	0.0518	0.0527	0.0538	0.0552	0.0568	0.0587	0.0611
(3.11)VII78	r/s	Wn S.P.			0.5432	0.9056	1.3413	1.7826	2.2226	2.6583	3.0862	3.5011	3.9026	4.2642	4.5713	4.8016
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-2.476	-2.505	-2.554	-2.626	-2.721	-2.844	-2.999	-3.193	-3.427	-3.644	-3.831	-4.000
"	/s	XTu			0.2089	-0.057	-0.016	-0.011	-0.010	-0.011	-0.012	-0.014	-0.015	-0.017	-0.018	-0.020
"	/s	Xu			-0.231	0.3623	0.0297	-0.002	-0.013	-0.019	-0.023	-0.028	-0.031	-0.035	-0.039	-0.043
"	/s	X[-]u			-0.022	0.3043	0.0135	-0.014	-0.023	-0.030	-0.036	-0.042	-0.047	-0.052	-0.058	-0.063
T6.8one445	ft/s2	YB			-2.476	-9.918	-22.36	-39.86	-62.51	-90.40	-123.6	-162.4	-206.8	-257.0	-313.2	-375.5
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			1.4264	5.7132	12.883	22.973	36.037	52.137	71.353	93.770	119.48	148.58	181.18	217.34
"	ft/s	Yp			1.1429	0.5678	0.0622	-0.291	-0.582	-0.844	-1.090	-1.329	-1.563	-1.773	-1.964	-2.147
"	"	Yr			0.0772	2.2227	3.4482	4.6033	5.7588	6.9273	8.1131	9.3189	10.546	11.800	13.081	14.386
T6.3one413	ft/s2	Za			-31.13	-80.91	-178.3	-319.6	-507.1	-745.4	-1040.	-1400.	-1834.	-2358.	-2990.	-3753.
"	ft/s	Za[.]			-0.594	-1.202	-1.837	-2.512	-3.247	-4.061	-4.981	-6.038	-7.276	-8.751	-10.53	-12.74
"	ft/s2	ZdE			-0.732	-2.943	-6.676	-12.00	-19.04	-27.94	-38.89	-52.15	-68.04	-86.97	-109.4	-136.1
(3.27)VII89		Zeta D			ERR	0.2086	0.2122	0.2120	0.2124	0.2126	0.2130	0.2140	0.2150	0.2160	0.2168	0.2177
(3.10)VII78		Zeta P	(6.113)one430		0.2235	-3.053	-0.134	0.1388	0.2342	0.2961	0.3467	0.3913	0.4310	0.4663	0.4966	0.5212
(3.12)VII78		Zeta S.P.			1.0687	1.0667	1.0789	1.0958	1.1184	1.1480	1.1860	1.2346	1.2948	1.3766	1.4866	1.6371
T6.3one413	ft/s	Zq			-1.660	-3.336	-5.046	-6.807	-8.639	-10.56	-12.60	-14.79	-17.15	-19.74	-22.59	-25.76
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.022	-0.027	-0.033	-0.039	-0.046	-0.055	-0.064	-0.076

Table C.4.4 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: DASH-IN (M = 0.55, W = 39,508 #, h = 1,000 ft)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			55.63	111.26	166.89	222.52	278.15	333.78	389.41	445.04	500.67	556.3	611.93	667.56
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			0.9646	1.6367	3.4452	6.1228	9.6942	14.236	19.863	26.726	35.025	45.024	57.073	71.640
Pitch angle	d,r	theta1	0	0												
(B4)one538	sec	T2P			-14.05	4.1438	39.758	-942.1	-117.4	-80.06	-64.57	-55.17	-48.52	-43.41	-39.31	-35.93
(6.141)one446		A1	(Ixz/Ixx)s		0.4741	-0.472	-0.214	-0.026	0.0654	0.1141	0.1428	0.1611	0.1734	0.1794	0.1817	0.1825
"		B1	(Ixz/Izz)s		0.3318	-0.307	-0.089	-0.010	0.0262	0.0462	0.0582	0.0661	0.0714	0.0741	0.0751	0.0754
T6.8one445	/s2	LB			-1.744	-0.798	-2.348	-4.419	-6.997	-10.11	-13.81	-18.13	-23.05	-28.36	-34.02	-40.12
"	/s2	LdA			0.9928	4.1776	12.715	23.773	37.946	55.957	78.578	106.79	141.93	186.03	241.89	313.67
"	/s2	LdR			-0.285	-1.063	-0.886	-0.052	1.0653	2.4273	4.0387	5.9100	8.0518	10.328	12.741	15.342
"	/s	Lp			-5.105	-3.218	-5.738	-7.922	-10.20	-12.72	-15.14	-17.88	-21.00	-24.80	-29.49	-35.46
"	/s	Lr			9.1976	4.9321	5.3919	5.3310	5.4430	5.7143	6.0912	6.5390	7.0378	7.5473	8.0640	8.5939
T6.3one413	/s2	Ma			-0.157	-0.627	-1.394	-2.432	-3.701	-5.135	-6.639	-8.065	-9.251	-9.762	-9.126	-6.668
"	/s	Ma[.]			-0.145	-0.293	-0.448	-0.613	-0.793	-0.992	-1.216	-1.475	-1.777	-2.137	-2.574	-3.113
"	/s2	MdE			-0.182	-0.734	-1.666	-2.996	-4.753	-6.973	-9.705	-13.01	-16.97	-21.70	-27.31	-33.97
"	/s	Mq			-0.454	-0.912	-1.380	-1.861	-2.360	-2.885	-3.440	-4.034	-4.675	-5.375	-6.146	-7.002
"	/s2	MTa														
"	/ft/s	MTu			0.0078	-0.007	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0012	0.0006	0.0002	-0.000	-0.000	-0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003
T6.8one445	/s2	NB			-0.567	1.5727	3.5265	6.2514	9.7359	14.059	19.212	25.138	31.903	39.522	48.196	57.827
"	/s2	NdA			-0.767	-0.753	-0.660	-0.670	-0.696	-0.731	-0.775	-0.830	-0.901	-0.976	-1.058	-1.155
"	/s2	NdR			0.3011	-1.224	-2.700	-4.796	-7.518	-10.87	-14.88	-19.56	-24.93	-31.01	-37.81	-45.36
"	/s	Np			0.1054	-0.392	-0.242	-0.114	0.0300	0.2022	0.4060	0.6424	0.9107	1.2036	1.5192	1.8558
"	/s	Nr			-0.211	-0.445	-0.739	-0.991	-1.241	-1.492	-1.747	-2.007	-2.271	-2.539	-2.815	-3.096
"	/s2	NTB														
(6.173)one458	s	TR			0.1958	0.3107	0.1742	0.1262	0.0980	0.0785	0.0660	0.0559	0.0475	0.0403	0.0339	0.0281
(3.24)VII88		LBNr-NBLr>0			yes	no	no	no	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			0.2498	-0.144	-0.124	-0.109	-0.099	-0.090	-0.082	-0.076	-0.070	-0.065	-0.059	-0.054
(6.161)one454	s	TS			0.3604	-0.208	-0.179	-0.158	-0.143	-0.130	-0.119	-0.110	-0.101	-0.094	-0.086	-0.079
(3.26)VII89	r/s	WnD			ERR	1.2568	1.8821	2.5059	3.1275	3.7583	4.3935	5.0259	5.6622	6.3024	6.9598	7.6237

Table C.4.4 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVES
FLIGHT CONDITION: DASH-IN (M = 0.55, W = 39,508 #, h = 1,000 ft)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			ERR	0.2502	0.4108	0.5509	0.6897	0.8295	0.9710	1.1156	1.2626	1.4118	1.5648	1.7208
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0489	0.0491	0.0494	0.0498	0.0504	0.0511	0.0520	0.0531	0.0544	0.0560	0.0579	0.0603
(3.11)VII78	r/s	Wn S.P.			0.6413	1.0292	1.5201	2.0199	2.5195	3.0157	3.5050	3.9825	4.4470	4.8744	5.2507	5.5541
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-1.830	-1.846	-1.875	-1.915	-1.969	-2.039	-2.126	-2.234	-2.363	-2.490	-2.608	-2.721
"	/s	XTu			0.2689	-0.254	-0.023	-0.011	-0.008	-0.008	-0.008	-0.009	-0.009	-0.010	-0.011	-0.012
"	/s	Xu			-0.367	0.5890	0.0586	0.0100	-0.003	-0.009	-0.012	-0.016	-0.018	-0.021	-0.023	-0.025
"	/s	X[-]u			-0.098	0.3345	0.0348	-0.001	-0.011	-0.017	-0.021	-0.025	-0.028	-0.031	-0.035	-0.038
T6.8one445	ft/s2	YB			-1.520	-6.090	-13.73	-24.47	-38.38	-55.51	-75.93	-99.74	-127.0	-157.8	-192.3	-230.6
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			0.8759	3.5083	7.9111	14.107	22.129	32.016	43.815	57.580	73.370	91.242	111.25	133.46
"	ft/s	Yp			0.3941	0.7024	0.2923	0.0126	-0.204	-0.390	-0.560	-0.720	-0.874	-1.011	-1.134	-1.253
"	"	Yr			-0.593	1.2421	2.1252	2.8691	3.5946	4.3232	5.0611	5.8109	6.5740	7.3535	8.1494	8.9607
T6.3one413	ft/s2	Za			-31.03	-52.66	-110.8	-196.9	-311.9	-458.0	-639.0	-859.8	-1126.	-1448.	-1836.	-2304.
"	ft/s	Za[.]			-0.369	-0.746	-1.140	-1.559	-2.015	-2.521	-3.091	-3.748	-4.516	-5.431	-6.541	-7.910
"	ft/s2	ZdE			-0.449	-1.807	-4.099	-7.373	-11.69	-17.15	-23.88	-32.02	-41.78	-53.40	-67.21	-83.59
(3.27)VII89		Zeta D			ERR	0.1990	0.2182	0.2198	0.2205	0.2207	0.2210	0.2219	0.2229	0.2240	0.2248	0.2257
(3.10)VII78		Zeta P	(6.113)one430		1.0069	-3.404	-0.352	0.0147	0.1169	0.1692	0.2063	0.2365	0.2624	0.2849	0.3041	0.3196
(3.12)VII78		Zeta S.P.			0.9023	0.8160	0.8200	0.8317	0.8484	0.8703	0.8984	0.9342	0.9786	1.0378	1.1161	1.2215
T6.3one413	ft/s	Zq			-1.225	-2.461	-3.721	-5.015	-6.359	-7.766	-9.254	-10.84	-12.55	-14.42	-16.46	-18.74
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.021	-0.027	-0.032	-0.039	-0.046	-0.054	-0.063	-0.075

Table C.4.5 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: MANEUVER (W = 30,220 #, n = 5, h = 1,000 ft, M = 0.35)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			55.63	111.26	166.89	222.52	278.15	333.78	389.41	445.04	500.67	556.3	611.93	667.56
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			11.853	4.7833	5.6756	8.6610	13.091	18.900	26.178	35.099	45.914	58.962	74.696	93.727
Pitch angle	d,r	theta1	0	0												
(B4)one538	sec	T2P			-6.374	0.2184	-14.97	-3.231	-3.300	-3.662	-4.075	-4.485	-4.872	-5.220	-5.523	-5.789
(6.141)one446		A1	(Ixz/Ixx)s		0.2401	-0.486	-0.172	-0.002	0.0774	0.1202	0.1456	0.1618	0.1729	0.1775	0.1784	0.1780
"		B1	(Ixz/Izz)s		0.4810	-0.246	-0.065	-0.001	0.0285	0.0446	0.0544	0.0607	0.0650	0.0669	0.0672	0.0671
T6.8one445	/s2	LB			-5.215	-10.13	-13.92	-16.30	-19.03	-22.31	-26.27	-31.01	-36.32	-42.17	-48.40	-55.08
"	/s2	LdA			0.5969	4.7740	13.372	24.645	39.295	58.002	81.537	110.91	147.51	193.45	251.64	326.41
"	/s2	LdR			-0.288	-0.844	-0.437	0.4451	1.5918	2.9907	4.6504	6.5812	8.7935	11.147	13.645	16.338
"	/s	Lp			-44.87	-14.06	-9.827	-9.848	-11.40	-13.67	-16.02	-18.78	-21.98	-25.90	-30.76	-36.96
"	/s	Lr			23.055	23.226	20.195	16.692	14.614	13.448	12.832	12.566	12.539	12.661	12.894	13.223
T6.3one413	/s2	Ma			-0.106	-0.421	-0.924	-1.581	-2.335	-3.102	-3.758	-4.119	-3.973	-2.806	-0.049	5.1078
"	/s	Ma[.]			-0.154	-0.313	-0.478	-0.654	-0.845	-1.057	-1.297	-1.572	-1.895	-2.279	-2.744	-3.319
"	/s2	MdE			-0.194	-0.783	-1.776	-3.194	-5.067	-7.433	-10.34	-13.87	-18.10	-23.13	-29.11	-36.21
"	/s	Mq			-0.480	-0.965	-1.460	-1.968	-2.497	-3.051	-3.639	-4.267	-4.945	-5.685	-6.500	-7.406
"	/s2	MTa														
"	/ft/s	MTu			0.1629	-0.120	-0.032	-0.018	-0.013	-0.010	-0.008	-0.007	-0.006	-0.006	-0.005	-0.005
"	/ft/s	Mu			0.0073	0.0057	0.0050	0.0045	0.0042	0.0039	0.0037	0.0033	0.0036	0.0037	0.0037	0.0042
T6.8one445	/s2	NB			-0.483	1.5064	3.3070	5.8441	9.0901	13.118	17.921	23.442	29.746	36.846	44.933	53.913
"	/s2	NdA			-5.784	-2.926	-2.712	-2.749	-2.828	-2.930	-3.057	-3.216	-3.414	-3.648	-3.931	-4.285
"	/s2	NdR			0.2071	-1.156	-2.535	-4.497	-7.044	-10.18	-13.93	-18.31	-23.33	-29.01	-35.37	-42.43
"	/s	Np			0.0693	-0.296	-0.178	-0.070	0.0588	0.2167	0.4061	0.6271	0.8790	1.1547	1.4524	1.7703
"	/s	Nr			-0.068	-0.446	-0.690	-0.917	-1.146	-1.377	-1.611	-1.851	-2.095	-2.343	-2.597	-2.857
"	/s2	NTB														
(6.173)one458	s	TR			0.0222	0.0711	0.1017	0.1015	0.0876	0.0731	0.0623	0.0532	0.0454	0.0386	0.0325	0.0270
(3.24)VII88		LBNr-NBLr>0			yes	no	no	no	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			0.3214	-0.247	-0.175	-0.136	-0.114	-0.098	-0.087	-0.079	-0.072	-0.067	-0.061	-0.056
(6.161)one454	s	TS			0.4637	-0.356	-0.253	-0.197	-0.165	-0.142	-0.126	-0.114	-0.105	-0.096	-0.089	-0.081
(3.26)VII89	r/s	WnD			ERR	1.2308	1.8238	2.4246	3.0241	3.6331	4.2464	4.8570	5.4715	6.0900	6.7252	7.3669

Table C.4.5 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: MANEUVER (W = 30,220 #, n = 5, h = 1,000 ft, M = 0.35)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			ERR	0.2589	0.3988	0.5306	0.6633	0.7973	0.9333	1.0723	1.2137	1.3571	1.5044	1.6545
(3.9)VII78	r/s	Wn P	(6.112)one430		0.1094	0.1098	0.1105	0.1114	0.1127	0.1143	0.1163	0.1187	0.1217	0.1252	0.1296	0.1349
(3.11)VII78	r/s	Wn S.P.			1.8442	1.3256	1.5882	2.0116	2.4732	2.9432	3.4102	3.8662	4.3088	4.7111	5.0576	5.3243
T6.3one413	ft/s2	Xa			90.441	90.055	89.403	88.470	87.235	85.669	83.733	81.376	78.532	75.115	71.010	66.069
"	ft/s2	XdE			-12.30	-12.38	-12.50	-12.67	-12.90	-13.19	-13.54	-13.98	-14.48	-15.05	-15.67	-16.34
"	/s	XTu			6.7713	-4.996	-1.330	-0.777	-0.558	-0.440	-0.366	-0.315	-0.278	-0.251	-0.229	-0.212
"	/s	Xu			-6.988	11.342	1.2382	0.3482	0.1380	0.0619	0.0265	0.0069	-0.005	-0.014	-0.021	-0.026
"	/s	X[-]u			-0.217	6.3462	-0.092	-0.429	-0.420	-0.378	-0.340	-0.309	-0.284	-0.265	-0.250	-0.239
T6.8one445	ft/s2	YB			-1.988	-7.962	-17.95	-32.00	-50.18	-72.57	-99.27	-130.3	-166.0	-206.3	-251.4	-301.4
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			1.1451	4.5866	10.342	18.443	28.930	41.856	57.281	75.278	95.920	119.28	145.45	174.48
"	ft/s	Yp			0.8652	0.6380	0.1793	-0.134	-0.385	-0.607	-0.812	-1.009	-1.201	-1.372	-1.527	-1.676
"	"	Yr			-0.310	1.7267	2.7615	3.6987	4.6284	5.5666	6.5181	7.4855	8.4702	9.4763	10.503	11.550
T6.3one413	ft/s2	Za			-381.3	-153.9	-182.6	-278.6	-421.2	-608.1	-842.2	-1129.	-1477.	-1897.	-2403.	-3015.
"	ft/s	Za[.]			-0.476	-0.964	-1.472	-2.014	-2.603	-3.255	-3.992	-4.840	-5.832	-7.014	-8.447	-10.21
"	ft/s2	ZdE			-0.587	-2.362	-5.360	-9.639	-15.29	-22.43	-31.22	-41.86	-54.62	-69.81	-87.86	-109.2
(3.27)VII89		Zeta D			ERR	0.2103	0.2186	0.2188	0.2193	0.2194	0.2197	0.2207	0.2218	0.2228	0.2237	0.2245
(3.10)VII78		Zeta P	(6.113)one430		0.9932	-28.88	0.4186	1.9239	1.8628	1.6548	1.4618	1.3011	1.1686	1.0597	0.9681	0.8873
(3.12)VII78		Zeta S.P.			2.0309	1.0040	0.9547	0.9632	0.9820	1.0076	1.0408	1.0834	1.1361	1.2072	1.3022	1.4314
T6.3one413	ft/s	Zq			-1.458	-2.929	-4.429	-5.973	-7.576	-9.258	-11.03	-12.94	-14.99	-17.23	-19.70	-22.44
"	/s	Zu			-0.020	-0.041	-0.063	-0.085	-0.109	-0.135	-0.163	-0.195	-0.230	-0.271	-0.319	-0.377

Table C.4.6 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: DASH-OUT (W = 20,932 #, h = 1,000 ft, M = 0.55)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			55.63	111.26	166.89	222.52	278.15	333.78	389.41	445.04	500.67	556.3	611.93	667.56
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			1.0134	2.8877	6.4133	11.506	18.265	26.849	37.475	50.432	66.098	84.973	107.71	135.21
Pitch angle	d,r	thetal	0	0												
(B4)one538	sec	T2P			44.842	5.3094	196.90	-76.28	-49.19	-39.08	-32.99	-28.70	-25.45	-22.87	-20.76	-19.01
(6.141)one446		A1	(Ixz/Ixx)s		-0.157	-0.423	-0.101	0.0357	0.0990	0.1329	0.1530	0.1659	0.1748	0.1774	0.1765	0.1744
"		B1	(Ixz/Izz)s		-0.406	-0.167	-0.034	0.0120	0.0335	0.0452	0.0523	0.0569	0.0601	0.0610	0.0607	0.0599
T6.8one445	/s2	LB			-0.233	-1.050	-2.672	-4.804	-7.515	-10.82	-14.77	-19.38	-24.64	-30.30	-36.35	-42.88
"	/s2	LdA			0.5384	5.5307	14.074	25.595	40.773	60.240	84.772	115.41	153.59	201.53	262.26	340.29
"	/s2	LdR			-0.260	-0.534	0.0491	0.9673	2.1445	3.5853	5.2993	7.2965	9.5867	12.026	14.618	17.412
"	/s	Lp			-1.280	-3.783	-6.192	-8.461	-10.92	-13.68	-16.33	-19.32	-22.72	-26.86	-31.97	-38.47
"	/s	Lr			2.6236	4.0088	4.1406	4.3444	4.7151	5.1883	5.7248	6.3037	6.9137	7.5180	8.1165	8.7178
T6.3one413	/s2	Ma			-0.047	-0.180	-0.374	-0.583	-0.733	-0.719	-0.381	0.5069	2.2134	5.3471	10.590	18.911
"	/s	Ma[.]			-0.166	-0.335	-0.513	-0.701	-0.907	-1.134	-1.391	-1.686	-2.032	-2.444	-2.943	-3.560
"	/s2	MdE			-0.208	-0.839	-1.905	-3.426	-5.435	-7.973	-11.09	-14.88	-19.41	-24.81	-31.23	-38.84
"	/s	Mq			-0.512	-1.029	-1.556	-2.098	-2.662	-3.252	-3.878	-4.547	-5.270	-6.058	-6.926	-7.891
"	/s2	MTa														
"	/ft/s	MTu			0.0041	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0006	0.0000	-0.000	-0.000	-0.001	-0.001	-0.002	-0.002	-0.003	-0.003	-0.004	-0.004
T6.8one445	/s2	NB			0.1454	1.4121	3.0923	5.4630	8.4954	12.259	16.746	21.904	27.791	34.424	41.982	50.376
"	/s2	NdA			-0.813	-0.321	-0.317	-0.328	-0.344	-0.366	-0.394	-0.429	-0.474	-0.520	-0.567	-0.618
"	/s2	NdR			-0.205	-1.077	-2.376	-4.219	-6.607	-9.553	-13.06	-17.17	-21.87	-27.20	-33.17	-39.79
"	/s	Np			-0.307	-0.205	-0.121	-0.031	0.0834	0.2286	0.4049	0.6123	0.8495	1.1098	1.3914	1.6924
"	/s	Nr			-0.062	-0.428	-0.639	-0.847	-1.058	-1.272	-1.489	-1.711	-1.937	-2.166	-2.402	-2.642
"	/s2	NTB														
(6.173)one458	s	TR			0.7809	0.2643	0.1614	0.1181	0.0915	0.0730	0.0612	0.0517	0.0439	0.0372	0.0312	0.0259
(3.24)VII88		LBNr-NBLr>0			no	no	no	no	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			-0.484	-0.219	-0.186	-0.162	-0.144	-0.127	-0.114	-0.104	-0.094	-0.086	-0.079	-0.072
(6.161)one454	s	TS			-0.698	-0.316	-0.269	-0.234	-0.207	-0.184	-0.165	-0.150	-0.136	-0.125	-0.114	-0.104
(3.26)VII89	r/s	WnD			0.3842	1.1932	1.7659	2.3473	2.9275	3.5168	4.1105	4.7015	5.2962	5.8949	6.5101	7.1315

Table C.4.6 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: DASH-OUT (W = 20,932 #, h = 1,000 ft, M = 0.55)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			0.0569	0.2658	0.3975	0.5276	0.6595	0.7931	0.9286	1.0672	1.2080	1.3510	1.4978	1.6473
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0489	0.0491	0.0494	0.0498	0.0504	0.0511	0.0520	0.0531	0.0544	0.0560	0.0579	0.0603
(3.11)VII78	r/s	Wn S.P.			0.5894	1.0199	1.5162	2.0186	2.5215	3.0229	3.5201	4.0093	4.4915	4.9425	5.3515	5.7021
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-2.477	-2.509	-2.563	-2.640	-2.745	-2.880	-3.050	-3.262	-3.521	-3.757	-3.954	-4.129
"	/s	XTu			0.2286	-0.045	-0.015	-0.011	-0.011	-0.012	-0.014	-0.015	-0.017	-0.019	-0.021	-0.023
"	/s	Xu			-0.197	0.3061	0.0221	-0.006	-0.016	-0.022	-0.027	-0.032	-0.036	-0.041	-0.045	-0.049
"	/s	X[-]u			0.0309	0.2610	0.0070	-0.018	-0.028	-0.035	-0.042	-0.048	-0.054	-0.060	-0.066	-0.072
T6.8one445	ft/s2	YB			-2.870	-11.49	-25.91	-46.20	-72.45	-104.7	-143.3	-188.2	-239.7	-297.9	-363.0	-435.2
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			1.6532	6.6217	14.931	26.627	41.767	60.428	82.699	108.68	138.48	172.21	209.99	251.90
"	ft/s	Yp			1.2521	0.5035	-0.027	-0.406	-0.723	-1.011	-1.285	-1.552	-1.816	-2.051	-2.266	-2.474
"	"	Yr			0.3822	2.5731	3.9414	5.2558	6.5755	7.9111	9.2668	10.645	12.048	13.482	14.946	16.438
T6.3one413	ft/s2	Za			-32.60	-92.91	-206.3	-370.2	-587.6	-863.8	-1205.	-1622.	-2126.	-2733.	-3465.	-4350.
"	ft/s	Za[.]			-0.679	-1.374	-2.099	-2.871	-3.711	-4.642	-5.693	-6.901	-8.316	-10.00	-12.04	-14.56
"	ft/s2	ZdE			-0.848	-3.411	-7.738	-13.91	-22.07	-32.38	-45.07	-60.44	-78.86	-100.8	-126.8	-157.7
(3.27)VII89		Zeta D			0.1483	0.2227	0.2251	0.2247	0.2252	0.2255	0.2259	0.2269	0.2280	0.2291	0.2300	0.2309
(3.10)VII78		Zeta P	(6.113)one430		-0.315	-2.656	-0.071	0.1822	0.2793	0.3467	0.4037	0.4545	0.5001	0.5407	0.5758	0.6042
(3.12)VII78		Zeta S.P.			1.0726	1.0786	1.0901	1.1057	1.1266	1.1537	1.1883	1.2322	1.2858	1.3573	1.4513	1.5755
T6.3one413	ft/s	Zq			-1.897	-3.813	-5.767	-7.780	-9.874	-12.07	-14.40	-16.90	-19.60	-22.56	-25.81	-29.44
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.021	-0.027	-0.032	-0.039	-0.046	-0.054	-0.063	-0.075

Table C.4.7 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: LANDING (W = 20,932 #, h = SEALEVEL, M = 0.15)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
Mach		M			0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
M x a	fps	U			55.82	111.64	167.46	223.28	279.1	334.92	390.74	446.56	502.38	558.2	614.02	669.84
gravity	ft/s2	g	32.174													
(B5)one538	g's/rad	n/a			1.0280	2.9886	6.6475	11.929	18.938	27.839	38.857	52.292	68.537	88.108	111.69	140.20
Pitch angle	d,r	theta1	0	0												
(B4)one538	sec	T2P			29.883	5.5227	252.81	-72.09	-47.34	-37.74	-31.90	-27.76	-24.63	-22.13	-20.09	-18.39
(6.141)one446		A1	(Ixz/Ixx)s		-0.196	-0.272	-0.006	0.0941	0.1392	0.1630	0.1771	0.1862	0.1924	0.1941	0.1933	0.1917
"		B1	(Ixz/Izz)s		-0.397	-0.118	-0.002	0.0379	0.0567	0.0669	0.0730	0.0771	0.0798	0.0806	0.0802	0.0795
T6.8one445	/s2	LB			-0.257	-1.073	-2.586	-4.599	-7.174	-10.32	-14.08	-18.46	-23.47	-28.87	-34.64	-40.85
"	/s2	LdA			0.6335	5.6527	13.623	24.514	38.938	57.468	80.834	110.02	146.41	192.11	250.01	324.41
"	/s2	LdR			-0.301	-0.510	0.0855	0.9637	2.0844	3.4559	5.0879	6.9898	9.1711	11.496	13.965	16.628
"	/s	Lp			-1.453	-3.840	-5.969	-8.074	-10.39	-13.00	-15.51	-18.35	-21.59	-25.52	-30.37	-36.55
"	/s	Lr			2.9625	3.9818	3.9231	4.0930	4.4441	4.8961	5.4084	5.9606	6.5418	7.1178	7.6880	8.2608
T6.3one413	/s2	Ma			-0.041	-0.159	-0.331	-0.515	-0.649	-0.636	-0.337	0.4484	1.9580	4.7301	9.3684	16.729
"	/s	Ma[.]			-0.146	-0.296	-0.452	-0.618	-0.799	-1.000	-1.226	-1.487	-1.792	-2.155	-2.595	-3.138
"	/s2	MdE			-0.184	-0.742	-1.685	-3.031	-4.808	-7.053	-9.818	-13.16	-17.17	-21.95	-27.63	-34.36
"	/s	Mq			-0.451	-0.907	-1.372	-1.850	-2.346	-2.867	-3.419	-4.009	-4.646	-5.341	-6.106	-6.957
"	/s2	MTa														
"	/ft/s	MTu			0.0036	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
"	/ft/s	Mu			0.0005	-0.000	-0.000	-0.000	-0.001	-0.001	-0.002	-0.002	-0.002	-0.003	-0.003	-0.004
T6.8one445	/s2	NB			0.1840	1.5901	3.5314	6.2621	9.7527	14.085	19.248	25.183	31.959	39.588	48.279	57.930
"	/s2	NdA			-0.723	-0.348	-0.349	-0.363	-0.382	-0.407	-0.439	-0.479	-0.530	-0.582	-0.634	-0.691
"	/s2	NdR			-0.220	-1.212	-2.714	-4.836	-7.586	-10.97	-15.02	-19.74	-25.15	-31.28	-38.14	-45.76
"	/s	Np			-0.307	-0.224	-0.134	-0.033	0.0978	0.2637	0.4655	0.7030	0.9748	1.2730	1.5956	1.9404
"	/s	Nr			-0.073	-0.481	-0.728	-0.968	-1.210	-1.456	-1.705	-1.960	-2.220	-2.482	-2.753	-3.028
"	/s2	NTB														
(6.173)one458	s	TR			0.6878	0.2603	0.1675	0.1238	0.0961	0.0768	0.0644	0.0544	0.0463	0.0391	0.0329	0.0273
(3.24)VII88		LBNr-NBLr>0			no	no	no	no	no	no	no	no	no	no	no	no
(3.25)VII89	s	T2S			-0.386	-0.179	-0.151	-0.131	-0.116	-0.103	-0.092	-0.083	-0.076	-0.069	-0.063	-0.058
(6.161)one454	s	TS			-0.557	-0.259	-0.217	-0.189	-0.167	-0.148	-0.133	-0.120	-0.110	-0.100	-0.091	-0.083
(3.26)VII89	r/s	WnD			0.4317	1.2663	1.8874	2.5134	3.1370	3.7701	4.4074	5.0418	5.6802	6.3225	6.9823	7.6486

Table C.4.7 LONGITUDINAL AND LATERAL-DIRECTIONAL STABILITY DERIVATIVE
FLIGHT CONDITION: LANDING (W = 20,932 #, h = SEALEVEL, M = 0.15)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
VII297	r/s	WnDZetaD			0.0631	0.2941	0.4443	0.5913	0.7400	0.8905	1.0430	1.1989	1.3574	1.5182	1.6831	1.8511
(3.9)VII78	r/s	Wn P	(6.112)one430		0.0487	0.0489	0.0492	0.0496	0.0502	0.0509	0.0518	0.0529	0.0542	0.0558	0.0577	0.0601
(3.11)VII78	r/s	Wn S.P.			0.5562	0.9702	1.4435	1.9226	2.4026	2.8819	3.3583	3.8285	4.2939	4.7324	5.1352	5.4882
T6.3one413	ft/s2	Xa			18.088	18.011	17.880	17.694	17.447	17.133	16.746	16.275	15.706	15.023	14.202	13.213
"	ft/s2	XdE			-2.477	-2.510	-2.565	-2.644	-2.751	-2.889	-3.064	-3.281	-3.547	-3.787	-3.987	-4.163
"	/s	XTu			0.2367	-0.042	-0.014	-0.011	-0.011	-0.013	-0.014	-0.016	-0.018	-0.020	-0.022	-0.024
"	/s	Xu			-0.190	0.2936	0.0203	-0.007	-0.017	-0.023	-0.028	-0.033	-0.038	-0.042	-0.046	-0.051
"	/s	X[-]u			0.0463	0.2510	0.0054	-0.019	-0.029	-0.036	-0.043	-0.049	-0.056	-0.062	-0.068	-0.075
T6.8one445	ft/s2	YB			-2.976	-11.91	-26.87	-47.90	-75.12	-108.6	-148.6	-195.2	-248.5	-308.9	-376.4	-451.3
"	"	YdA			0	0	0	0	0	0	0	0	0	0	0	0
"	"	YdR			1.7142	6.8661	15.482	27.609	43.308	62.658	85.750	112.69	143.59	178.57	217.74	261.20
"	ft/s	Yp			1.2720	0.4864	-0.051	-0.436	-0.760	-1.056	-1.338	-1.612	-1.883	-2.126	-2.347	-2.561
"	"	Yr			0.4607	2.6653	4.0727	5.4299	6.7934	8.1737	9.5748	10.999	12.449	13.931	15.444	16.986
T6.3one413	ft/s2	Za			-33.07	-96.15	-213.8	-383.8	-609.3	-895.7	-1250.	-1682.	-2205.	-2834.	-3593.	-4510.
"	ft/s	Za[.]			-0.702	-1.420	-2.169	-2.967	-3.835	-4.797	-5.883	-7.131	-8.593	-10.33	-12.44	-15.05
"	ft/s2	ZdE			-0.879	-3.537	-8.023	-14.43	-22.88	-33.58	-46.74	-62.67	-81.77	-104.5	-131.5	-163.6
(3.27)VII89		Zeta D			0.1463	0.2322	0.2354	0.2352	0.2359	0.2362	0.2366	0.2378	0.2389	0.2401	0.2410	0.2420
(3.10)VII78		Zeta P	(6.113)one430		-0.475	-2.563	-0.055	0.1934	0.2913	0.3603	0.4190	0.4715	0.5187	0.5608	0.5971	0.6265
(3.12)VII78		Zeta S.P.			1.0703	1.0641	1.0743	1.0891	1.1091	1.1350	1.1680	1.2098	1.2608	1.3285	1.4171	1.5332
T6.3one413	ft/s	Zq			-1.960	-3.940	-5.960	-8.040	-10.20	-12.47	-14.88	-17.46	-20.26	-23.31	-26.67	-30.42
"	/s	Zu			-0.004	-0.008	-0.012	-0.017	-0.021	-0.027	-0.032	-0.038	-0.045	-0.054	-0.063	-0.075

Table C.5.1 LONGITUDINAL AIRPLANE TRANSFER FUNCTION
FLIGHT CONDITION: TAKE-OFF AT SEALEVEL, WEIGHT = 39,508 LBS, M = 0.15

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-102.8	-207.6	-316.3	-431.1	-554.6	-689.6	-839.9	-1010.	-1203.	-1410.	-1627.	-1854.
		Bu			-128.0	-391.0	-884.8	-1621.	-2643.	-4016.	-5835.	-8238.	-11401	-15430	-20480	-26829
		Cu			-2032.	-5325.	-11224	-21069	-36237	-58142	-88211	-1E+05	-2E+05	-2E+05	-3E+05	-4E+05
		Du			185.26	1290.2	6182.6	19791.	49777.	107434	209079	378181	648528	1E+06	2E+06	3E+06
(6.79)one417	Na	Aa			-0.466	-1.873	-4.251	-7.645	-12.12	-17.79	-24.76	-33.20	-43.32	-55.37	-69.69	-86.67
		Ba			-10.59	-84.16	-288.5	-692.3	-1372.	-2416.	-3924.	-6014.	-8827.	-12536	-17353	-23543
		Ca			-1.928	31.515	9.7467	-1.311	-16.59	-42.62	-85.83	-154.0	-257.5	-409.2	-626.2	-930.6
		Da			-0.153	0.1221	-0.638	-1.579	-3.140	-5.593	-9.297	-14.67	-22.67	-34.14	-50.67	-75.17
(6.81)one418	Ntheta	Atheta			-10.57	-85.04	-289.3	-693.9	-1375.	-2422.	-3933.	-6027.	-8847.	-12566	-17396	-23604
		Btheta			-7.719	-8.505	-182.4	-616.5	-1563.	-3382.	-6584.	-11909	-20415	-33653	-53896	-84524
		Ctheta			-1.157	14.973	6.0805	-2.162	-20.66	-62.33	-147.7	-309.7	-601.1	-1104.	-1949.	-3341.
(6.76)one416	D1	A			56.201	112.41	168.63	224.89	281.18	337.52	393.93	450.43	507.04	563.81	620.77	678.01
		B			71.113	153.11	425.57	775.55	1236.2	1822.4	2551.2	3444.7	4532.4	5852.8	7457.7	9416.2
		C			30.146	52.966	386.14	944.86	1850.5	3189.8	5037.0	7447.8	10474.	14036.	18014.	22168.
		D			9.4628	-52.48	-13.92	1.2866	20.787	52.822	104.07	180.58	291.05	437.28	620.22	835.82
		E			8.4842	-9.265	-1.142	-2.163	-6.175	-13.98	-26.93	-49.01	-76.21	-118.5	-181.8	-262.8
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.2 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITIONS: CRUISE #1 (M = 0.40) AND LOITER (M = 0.25) FOR [W = 39,508 #, h = 5,000 ft]

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-100.9	-203.6	-309.9	-421.6	-541.2	-671.1	-814.7	-975.9	-1157.	-1353.	-1559.	-1777.
		Bu			-119.0	-328.2	-736.2	-1345.	-2187.	-3315.	-4803.	-6756.	-9311.	-12568	-16664	-21827
		Cu			-1960.	-4940.	-10039	-18340	-30951	-49000	-73614	-1E+05	-1E+05	-2E+05	-3E+05	-3E+05
		Du			162.86	928.06	4315.6	13738.	34500.	74422.	144800	261885	449071	740581	1E+06	2E+06
(6.79)one417	Na	Aa			-0.387	-1.559	-3.537	-6.361	-10.09	-14.80	-20.60	-27.63	-36.04	-46.07	-57.99	-72.12
		Ba			-8.631	-70.92	-235.9	-566.2	-1122.	-1976.	-3210.	-4919.	-7220.	-10253	-14194	-19257
		Ca			-1.455	-58.84	10.035	1.2689	-9.798	-28.06	-58.12	-105.4	-177.1	-282.2	-432.6	-643.5
		Da			-0.188	2.2438	-0.545	-1.390	-2.777	-4.952	-8.231	-12.98	-20.04	-30.13	-44.63	-66.06
(6.81)one418	Ntheta	Atheta			-8.649	-69.53	-236.6	-567.4	-1125.	-1980.	-3216.	-4928.	-7234.	-10274	-14224	-19300
		Btheta			-6.555	-87.58	-124.1	-425.8	-1082.	-2341.	-4559.	-8245.	-14135	-23301	-37317	-58524
		Ctheta			-0.984	-23.02	5.3554	0.0857	-11.07	-35.86	-86.42	-182.0	-353.8	-650.0	-1147.	-1965.
(6.76)one416	D1	A			55.178	110.36	165.56	220.78	276.03	331.33	386.69	442.11	497.64	553.30	609.12	665.18
		B			62.086	271.43	352.61	644.92	1028.5	1516.4	2122.9	2866.4	3771.5	4870.3	6205.8	7835.6
		C			21.268	256.10	295.46	727.71	1424.0	2448.7	3853.0	5669.9	7925.6	10529.	13350.	16143.
		D			11.141	16.737	-13.59	-1.567	11.979	33.176	66.450	115.33	185.57	276.76	387.84	514.02
		E			14.033	-72.45	-0.847	-0.422	-2.078	-6.071	-13.20	-26.44	-41.86	-67.20	-106.5	-155.9
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.3 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: CRUISE #2 (M = 0.4, W = 20,932 #, h = 5,000 ft

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-137.3	-277.9	-425.1	-582.8	-755.3	-947.8	-1166.	-1420.	-1717.	-2031.	-2352.	-2684.
		Bu			-171.0	-584.4	-1337.	-2464.	-4045.	-6196.	-9088.	-12970	-18182	-24794	-32999	-43232
		Cu			-1987.	-5158.	-10781	-20131	-34534	-55363	-84034	-1E+05	-2E+05	-2E+05	-3E+05	-4E+05
		Du			179.63	1871.7	9364.4	30207.	76133.	164441	320124	579127	993204	2E+06	3E+06	4E+06
(6.79)one417	Na	Aa			-0.732	-2.943	-6.676	-12.00	-19.04	-27.94	-38.89	-52.15	-68.04	-86.97	-109.4	-136.1
		Ba			-9.923	-78.81	-271.2	-650.7	-1290.	-2272.	-3689.	-5654.	-8300.	-11789	-16321	-22148
		Ca			-0.811	24.522	3.9547	-8.540	-29.81	-67.97	-132.2	-234.2	-389.1	-616.6	-942.2	-1398.
		Da			-0.131	-0.113	-0.553	-1.304	-2.558	-4.537	-7.540	-11.91	-18.51	-28.05	-41.95	-62.89
(6.81)one418	Ntheta	Atheta			-9.889	-79.50	-270.5	-648.7	-1286.	-2264.	-3677.	-5635.	-8271.	-11747	-16263	-22066
		Btheta			-6.426	-33.73	-287.1	-947.4	-2396.	-5179.	-10081	-18233	-31258	-51528	-82524	-1E+05
		Ctheta			-0.547	17.818	3.8869	-13.15	-56.30	-155.7	-361.3	-753.0	-1458.	-2679.	-4734.	-8120.
(6.76)one416	D1	A			55.449	110.91	166.40	221.93	277.52	333.19	388.96	444.87	500.97	557.30	613.94	671.00
		B			64.954	178.32	474.34	860.84	1371.0	2020.2	2826.8	3815.0	5016.6	6474.0	8243.2	10399.
		C			17.613	25.066	288.25	706.23	1382.6	2381.5	3756.6	5546.5	7790.5	10408.	13296.	16258.
		D			4.1315	-28.47	-4.955	7.5555	28.167	64.368	123.30	211.90	339.10	506.37	712.84	950.09
		E			4.5398	-2.271	-3.240	-9.153	-20.98	-40.90	-71.80	-119.6	-183.1	-275.7	-408.0	-583.6
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.4 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-IN (M = 0.55, W = 39,508 #, h = 1,000 ft)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-102.4	-206.8	-315.0	-429.2	-551.9	-685.9	-834.8	-1003.	-1193.	-1398.	-1613.	-1838.
		Bu			-125.9	-377.6	-853.2	-1562.	-2546.	-3866.	-5615.	-7920.	-10952	-14814	-19659	-25752
		Cu			-2017.	-5243.	-10972	-20486	-35107	-56185	-85081	-1E+05	-2E+05	-2E+05	-3E+05	-4E+05
		Du			180.17	1207.9	5758.3	18415.	46305.	99932.	194472	351753	603202	994791	2E+06	3E+06
(6.79)one417	Na	Aa			-0.449	-1.807	-4.099	-7.373	-11.69	-17.15	-23.88	-32.02	-41.78	-53.40	-67.21	-83.59
		Ba			-10.18	-80.93	-277.3	-665.4	-1319.	-2323.	-3772.	-5780.	-8484.	-12049	-16680	-22630
		Ca			-1.900	28.655	9.8480	-0.715	-15.04	-39.31	-79.53	-142.9	-239.2	-380.3	-582.2	-865.3
		Da			-0.155	0.1950	-0.619	-1.542	-3.068	-5.465	-9.084	-14.33	-22.15	-33.34	-49.45	-73.33
(6.81)one418	Ntheta	Atheta			-10.16	-81.73	-278.1	-666.9	-1322.	-2328.	-3780.	-5793.	-8503.	-12077	-16720	-22686
		Btheta			-7.534	-8.808	-169.1	-573.1	-1454.	-3145.	-6124.	-11076	-18988	-31301	-50128	-78616
		Ctheta			-1.156	13.315	5.9569	-1.586	-18.32	-55.92	-132.9	-278.9	-541.4	-994.5	-1755.	-3009.
(6.76)one416	D1	A			55.999	112.00	168.03	224.07	280.16	336.30	392.50	448.78	505.18	561.73	618.47	675.47
		B			69.898	149.38	410.11	747.87	1192.2	1757.5	2460.4	3322.2	4371.1	5644.6	7192.4	9081.3
		C			29.111	53.950	366.17	897.11	1756.6	3026.5	4775.8	7054.8	9910.2	13257.	16974.	20818.
		D			9.7138	-49.78	-13.89	0.5868	18.692	48.181	95.200	165.19	266.15	399.29	565.02	758.97
		E			9.0869	-11.26	-1.045	-1.741	-5.206	-12.12	-23.73	-43.78	-68.25	-106.6	-164.4	-238.2
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.5 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: MANEUVER (W = 30,220 #, n = 5, h = 1,000 ft, M = 0.35)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-690.6	-1389.	-2104.	-2845.	-3622.	-4446.	-5330.	-6291.	-7336.	-8480.	-9725.	-11078
		Bu			-5183.	-3880.	-6807.	-11783	-18768	-28042	-40076	-55548	-75301	-1E+05	-1E+05	-2E+05
		Cu			-5036.	-13468	-36039	-79088	-1E+05	-3E+05	-4E+05	-6E+05	-8E+05	-1E+06	-1E+06	-2E+06
		Du			2388.1	3845.0	10276.	28151.	67521.	143209	276628	498573	853388	1E+06	2E+06	4E+06
(6.79)one417	Na	Aa			-0.587	-2.362	-5.360	-9.639	-15.29	-22.43	-31.22	-41.86	-54.62	-69.81	-87.86	-109.2
		Ba			-10.70	-71.59	-296.1	-713.8	-1414.	-2487.	-4037.	-6184.	-9073.	-12884	-17833	-24193
		Ca			-115.7	706.87	28.572	-263.9	-556.2	-905.1	-1336.	-1871.	-2540.	-3375.	-4421.	-5733.
		Da			-3.350	7.6533	1.0351	-4.447	-13.38	-27.66	-49.49	-81.42	-128.9	-196.8	-294.2	-437.1
(6.81)one418	Ntheta	Atheta			-10.83	-87.13	-296.4	-710.9	-1409.	-2481.	-4030.	-6176.	-9065.	-12874	-17823	-24184
		Btheta			-194.2	592.40	-290.3	-1140.	-2658.	-5362.	-9944.	-17382	-29087	-47106	-74446	-1E+05
		Ctheta			-825.0	997.83	34.232	-339.3	-871.1	-1710.	-3004.	-4940.	-7809.	-12008	-18142	-27107
(6.76)one416	D1	A			56.106	112.22	168.36	224.53	280.75	337.03	393.40	449.88	506.50	563.31	620.37	677.77
		B			428.92	-416.0	521.73	958.77	1469.1	2107.5	2898.6	3867.7	5046.7	6478.0	8217.1	10338.
		C			281.55	-1681.	469.37	1268.6	2260.9	3623.7	5441.5	7767.3	10648.	13999.	17697.	21500.
		D			-484.8	-525.3	293.78	567.91	868.50	1236.0	1678.8	2204.5	2797.7	3453.2	4144.0	4801.1
		E			2089.6	-566.4	-156.7	-122.4	-116.6	-116.1	-116.4	-127.4	-115.1	-116.1	-140.4	-143.5
(6.84)one420		A,B,C,D,E>0			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.6 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-OUT (W = 20,932 #, h = 1,000 ft, M = 0.55)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-139.5	-282.6	-433.1	-595.2	-773.8	-974.7	-1205.	-1474.	-1792.	-2127.	-2467.	-2816.
		Bu			-189.7	-676.0	-1553.	-2871.	-4726.	-7265.	-10699	-15341	-21619	-29579	-39423	-51655
		Cu			-2052.	-5516.	-11905	-22751	-39662	-64333	-98554	-1E+05	-2E+05	-3E+05	-4E+05	-5E+05
		Du			217.92	2490.8	12555.	40553.	102247	220872	430003	777925	1E+06	2E+06	4E+06	6E+06
(6.79)one417	Na	Aa			-0.848	-3.411	-7.738	-13.91	-22.07	-32.38	-45.07	-60.44	-78.86	-100.8	-126.8	-157.7
		Ba			-11.62	-92.84	-318.9	-765.2	-1517.	-2671.	-4338.	-6649.	-9760.	-13863	-19193	-26045
		Ca			-0.274	24.712	2.6107	-13.14	-41.37	-92.50	-178.8	-315.9	-524.1	-830.0	-1267.	-1881.
		Da			-0.159	-0.139	-0.587	-1.369	-2.677	-4.745	-7.893	-12.48	-19.47	-29.61	-44.47	-67.05
(6.81)one418	Ntheta	Atheta			-11.62	-93.45	-318.0	-762.5	-1511.	-2661.	-4322.	-6623.	-9722.	-13808	-19115	-25937
		Btheta			-7.086	-52.80	-387.6	-1273.	-3219.	-6957.	-13543	-24494	-41990	-69219	-1E+05	-2E+05
		Ctheta			-0.268	20.315	2.8109	-22.53	-88.39	-240.7	-555.9	-1156.	-2239.	-4113.	-7266.	-12464
(6.76)one416	D1	A			56.309	112.63	168.98	225.39	281.86	338.42	395.10	451.94	508.98	566.30	623.97	682.12
		B			68.640	215.54	550.84	998.06	1589.3	2341.7	3276.6	4422.0	5814.9	7504.1	9554.9	12054.
		C			17.139	51.244	377.86	920.55	1806.2	3124.5	4957.4	7375.5	10459.	14164.	18434.	23138.
		D			3.5021	-31.12	-4.068	13.363	44.081	98.947	189.20	326.73	526.77	796.91	1143.7	1566.9
		E			5.0489	-2.308	-4.896	-13.68	-30.54	-58.48	-101.4	-167.0	-254.8	-381.5	-561.1	-800.1
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.5.7 LONGITUDINAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: LANDING (W = 20,932 #, h = SEALEVEL, M = 0.15)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.77)one417	Nu	Au			-140.0	-283.8	-435.1	-598.3	-778.5	-981.7	-1215.	-1488.	-1812.	-2153.	-2498.	-2851.
		Bu			-180.6	-642.6	-1476.	-2729.	-4495.	-6911.	-10182	-14605	-20592	-28174	-37532	-49139
		Cu			-2029.	-5314.	-11199	-21054	-36318	-58517	-89269	-1E+05	-2E+05	-2E+05	-3E+05	-4E+05
		Du			195.52	2280.3	11512.	37193.	93782.	202591	394417	713550	1E+06	2E+06	3E+06	5E+06
(6.79)one417	Na	Aa			-0.879	-3.537	-8.023	-14.43	-22.88	-33.58	-46.74	-62.67	-81.77	-104.5	-131.5	-163.6
		Ba			-10.30	-82.31	-283.1	-679.3	-1347.	-2371.	-3851.	-5903.	-8665.	-12307	-17040	-23123
		Ca			-0.076	21.090	1.8830	-12.37	-38.19	-85.07	-164.2	-290.0	-481.0	-761.7	-1163.	-1726.
		Da			-0.143	-0.123	-0.507	-1.178	-2.301	-4.078	-6.787	-10.74	-16.77	-25.53	-38.38	-57.96
(6.81)one418	Ntheta	Atheta			-10.31	-82.95	-282.2	-676.8	-1342.	-2362.	-3836.	-5879.	-8630.	-12256	-16968	-23022
		Btheta			-6.189	-49.87	-355.9	-1168.	-2953.	-6381.	-12422	-22467	-38515	-63491	-1E+05	-2E+05
		Ctheta			-0.144	17.879	2.0478	-21.82	-84.16	-228.5	-527.2	-1096.	-2122.	-3899.	-6887.	-11814
(6.76)one416	D1	A			56.522	113.06	169.62	226.24	282.93	339.71	396.62	453.69	510.97	568.53	626.46	684.89
		B			63.869	202.27	518.75	939.97	1496.6	2204.9	3084.7	4162.3	5472.1	7060.0	8986.7	11334.
		C			14.176	46.723	344.37	839.49	1648.5	2854.8	4535.8	6760.6	9609.4	13052.	17060.	21536.
		D			2.8093	-27.13	-3.180	13.006	41.934	93.783	179.27	309.91	500.48	759.31	1094.2	1507.8
		E			4.4842	-2.015	-4.609	-12.83	-28.48	-54.34	-94.02	-154.4	-235.4	-352.0	-517.1	-736.9
(6.84)one420		A,B,C,D,E>0			YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table C.6.1 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTION
FLIGHT CONDITION: TAKE-OFF AT SEALEVEL, WEIGHT = 39,508 LBS, M = 0.15

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			26.469	229.45	295.21	185.39	-125.4	-696.9	-1611.	-2978.	-4941.	-7581.	-11116	-15928
		CB			219.96	621.02	1610.6	2613.3	2890.3	932.21	-6054.	-22337	-54648	-1E+05	-2E+05	-4E+05
		DB			-215.9	-54.48	209.77	696.19	1498.6	2739.8	4573.6	7205.6	10899.	16037.	23186.	33143.
(6.146)one447	NB	AB			0.7486	3.1340	8.0662	14.626	22.899	33.010	45.040	59.054	75.118	93.335	113.77	136.46
rudder		BB			-9.653	123.14	509.04	1230.8	2405.0	4163.4	6626.0	9947.6	14286.	19853.	26876.	35634.
		CB			-82.27	416.41	2748.2	9100.7	22941.	49507.	93698.	165527	277772	452114	720138	1E+06
		DB			82.186	-222.4	-513.1	-864.8	-1341.	-1988.	-2847.	-3960.	-5371.	-7109.	-9213.	-11731
(6.148)one448	Ntheta	Atheta			31.257	533.66	2239.6	5508.0	10962.	19392.	31776.	49365.	73828.	107545	153853	217682
aileron		Btheta			-373.7	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-112.4	719.25	7827.2	35081.	109784	281704	632290	1E+06	2E+06	4E+06	8E+06	1E+07
(6.148)one448	Ntheta	Atheta			-9.181	-54.00	-48.87	23.320	173.84	420.88	785.10	1288.3	1953.6	2770.2	3750.4	4920.6
rudder		Btheta			140.70	-780.6	-2700.	-6067.	-11758	-20916	-34945	-55545	-84742	-1E+05	-2E+05	-2E+05
		Ctheta			36.242	-326.9	-1725.	-5234.	-12886	-27858	-54971	-1E+05	-2E+05	-3E+05	-5E+05	-7E+05
(6.150)one448	Npsi	Apsi			-25.94	-228.7	-295.3	-188.0	118.19	682.02	1585.1	2934.5	4873.2	7480.7	10971.	15723.
aileron		Bpsi			-203.7	-486.8	-1219.	-1865.	-1642.	1024.7	9023.3	26755.	61155.	122282	225681	395216
		Cpsi			-6.574	-22.21	-88.48	-210.3	-324.8	-191.6	806.15	3880.9	11284.	26938.	57435.	113807
		Dpsi			-58.13	212.84	1505.7	5042.9	12609.	26950.	51835.	92315.	155883	253335	401984	625792
(6.150)one448	Npsi	Apsi			10.849	-106.0	-456.7	-1110.	-2166.	-3736.	-5933.	-8875.	-12684	-17500	-23459	-30695
rudder		Bpsi			75.922	-439.4	-2813.	-9281.	-23368	-50391	-95357	-2E+05	-3E+05	-5E+05	-7E+05	-1E+06
		Cpsi			-0.143	-5.025	-53.52	-249.5	-823.1	-2182.	-4911.	-10172	-19645	-36259	-64020	-1E+05
		Dpsi			21.125	-90.94	-320.6	-729.6	-1436.	-2588.	-4378.	-7070.	-10912	-16193	-23116	-32081
(6.145)one447	D2	A			46.013	96.180	164.66	223.25	278.53	333.03	387.36	441.69	496.04	550.68	605.55	660.54
		B			86.283	578.80	1205.2	2089.1	3293.2	4874.2	6728.1	9029.8	11867.	15481.	20131.	26238.
		C			-68.63	638.24	1722.9	3677.5	6901.8	11849.	18690.	28100.	40767.	57972.	81526.	113935
		D			-103.4	ERR	ERR	12177.	29965.	63985.	120258	210699	351167	568412	904911	1E+06

Table C.6.1 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTION
FLIGHT CONDITION: TAKE-OFF AT SEALEVEL, WEIGHT = 39,508 LBS, M = 0.15

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.84)one449		E			170.44	-253.1	-582.7	-976.8	-1500.	-2215.	-3162.	-4365.	-5882.	-7739.	-10028	-12772
		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.4046	0.8064	1.2022	1.5881	1.9589	2.3076	2.6237	2.8919	3.0972	3.1815	3.0762	2.6295

Table C.6.2 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITIONS: CRUISE #1 (M = 0.40) AND LOITER (M = 0.25) FOR [W = 39,508 #, h = 5,000 ft]

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			29.936	219.21	317.77	263.07	38.028	-400.5	-1118.	-2203.	-3772.	-5890.	-8733.	-12613
		CB			311.14	488.92	1313.8	2212.5	2657.1	1619.9	-2832.	-13626	-35397	-74873	-1E+05	-3E+05
		DB			-254.6	-77.10	112.83	462.93	1034.1	1912.5	3207.0	5063.1	7666.4	11286.	16322.	23335.
(6.146)one447	NB	AB			0.7427	2.5116	6.6067	12.151	19.080	27.516	37.538	49.206	62.576	77.734	94.737	113.62
rudder		BB			-8.526	89.688	402.47	992.87	1946.2	3368.0	5356.1	8033.1	11524.	15994.	21618.	28609.
		CB			-111.8	256.15	1860.8	6303.9	15955.	34439.	65148.	115016	192897	313802	499603	785605
		DB			104.99	-162.8	-403.3	-679.6	-1037.	-1515.	-2142.	-2949.	-3967.	-5218.	-6730.	-8536.
(6.148)one448	Ntheta	Atheta			58.641	398.90	1794.0	4499.5	8987.8	15905.	26052.	40455.	60478.	88066.	125949	178160
aileron		Btheta			-432.7	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-144.9	403.52	5138.0	23702.	74644.	191811	430602	876492	2E+06	3E+06	5E+06	9E+06
(6.148)one448	Ntheta	Atheta			-2.395	-53.10	-60.53	-10.09	106.44	302.65	595.13	1001.7	1541.3	2205.1	3003.2	3957.5
rudder		Btheta			176.67	-561.7	-2086.	-4686.	-8944.	-15665	-25838	-40649	-61515	-89898	-1E+05	-2E+05
		Ctheta			43.246	-227.8	-1299.	-3939.	-9544.	-20319	-39599	-72366	-1E+05	-2E+05	-3E+05	-5E+05
(6.150)one448	Npsi	Apsi			-29.50	-218.5	-317.5	-264.5	-42.68	390.56	1100.2	2173.0	3725.2	5820.3	8632.8	12469.
aileron		Bpsi			-275.1	-387.6	-995.6	-1595.	-1630.	-27.04	5215.8	17117.	40451.	82128.	152833	268953
		Cpsi			-6.796	-15.28	-59.27	-142.7	-230.7	-186.0	350.13	2080.1	6313.5	15329.	32960.	65618.
		Dpsi			-78.07	123.17	1007.7	3470.6	8731.5	18687.	35947.	64010.	108062	175578	278544	433553
(6.150)one448	Npsi	Apsi			13.647	-77.21	-364.7	-906.6	-1776.	-3065.	-4865.	-7275.	-10392	-14333	-19207	-25125
rudder		Bpsi			108.64	-276.7	-1911.	-6435.	-16260	-35062	-66307	-1E+05	-2E+05	-3E+05	-5E+05	-8E+05
		Cpsi			-0.112	-2.745	-30.63	-145.9	-484.2	-1284.	-2892.	-5988.	-11559	-21325	-37636	-64920
		Dpsi			25.517	-64.68	-246.7	-561.2	-1087.	-1929.	-3224.	-5155.	-7894.	-11649	-16559	-22902
(6.145)one447	D2	A			53.913	91.031	159.28	219.04	274.09	327.85	381.28	434.64	488.01	541.65	595.51	649.50
		B			384.43	495.26	1022.3	1761.9	2765.0	4081.2	5624.0	7539.2	9900.1	12907.	16776.	21858.
		C			51.480	493.29	1336.4	2817.2	5239.7	8944.9	14067.	21095.	30532.	43298.	60701.	84518.
		D			-108.6	ERR	ERR	8498.2	20900.	44555.	83624.	146352	243714	394212	627244	986727

Table C.6.2 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITIONS: CRUISE #1 (M = 0.40) AND LOITER (M = 0.25) FOR [W = 39,508 #, h = 5,000 ft]

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			214.15	-183.3	-457.8	-768.0	-1161.	-1690.	-2381.	-3253.	-4347.	-5684.	-7328.	-9298.
(6.84)one449		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.3691	0.7356	1.0967	1.4487	1.7869	2.1050	2.3934	2.6379	2.8253	2.9022	2.8061	2.3986

Table C.6.3 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: CRUISE #2 (M = 0.4, W = 20,932 #, h = 5,000 ft

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			50.318	137.66	151.06	50.269	-191.6	-620.8	-1297.	-2301.	-3736.	-5626.	-8107.	-11443
		CB			77.609	362.88	900.28	1406.8	1379.2	-219.6	-5263.	-16667	-39000	-78955	-1E+05	-3E+05
		DB			-74.66	15.334	178.16	485.91	1004.0	1811.6	3008.4	4728.8	7145.0	10507.	15188.	21708.
(6.146)one447	NB	AB			1.4262	5.1484	12.785	22.973	35.954	51.875	70.840	92.946	118.29	147.04	179.29	215.12
rudder		BB			3.8832	112.39	409.33	969.18	1892.2	3287.4	5245.5	7904.3	11404.	15951.	21777.	29188.
		CB			-5.724	315.07	1837.6	5964.8	15006.	32414.	61422.	108623	182437	297175	473678	745579
		DB			-3.892	-118.3	-258.9	-455.3	-740.1	-1140.	-1681.	-2391.	-3297.	-4421.	-5785.	-7420.
(6.148)one448	Ntheta	Atheta			24.831	514.50	1993.6	4848.0	9656.4	17118.	28099.	43713.	65442.	95401.	136553	193280
aileron		Btheta			-126.1	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-21.06	571.02	5204.4	22707.	70744.	181480	407550	830163	2E+06	3E+06	5E+06	8E+06
(6.148)one448	Ntheta	Atheta			-12.39	-12.29	32.638	143.51	339.34	642.34	1075.9	1664.4	2433.4	3385.3	4538.8	5922.6
rudder		Btheta			-7.567	-413.1	-1354.	-3173.	-6445.	-11908	-20483	-33286	-51644	-76919	-1E+05	-2E+05
		Ctheta			-0.079	-173.8	-868.1	-2755.	-7122.	-15991	-32458	-61171	-1E+05	-2E+05	-3E+05	-4E+05
(6.150)one448	Npsi	Apsi			-49.87	-137.7	-153.5	-57.92	174.76	589.36	1244.4	2216.1	3606.1	5434.6	7832.7	11053.
aileron		Bpsi			-68.04	-228.5	-541.9	-725.9	-230.4	2047.0	8078.7	20924.	45366.	88364.	160662	278787
		Cpsi			-3.289	-16.54	-68.84	-159.9	-210.8	55.631	1323.7	4946.1	13415.	31077.	65225.	128079
		Dpsi			-8.997	169.51	1014.5	3310.8	8243.0	17613.	33895.	60396.	102027	165874	263321	410076
(6.150)one448	Npsi	Apsi			-2.280	-90.12	-337.2	-798.9	-1551.	-2673.	-4246.	-6353.	-9083.	-12539	-16820	-22021
rudder		Bpsi			-1.519	-330.9	-1905.	-6173.	-15518	-33488	-63447	-1E+05	-2E+05	-3E+05	-5E+05	-8E+05
		Cpsi			-0.151	-6.043	-58.62	-267.1	-877.6	-2325.	-5239.	-10861	-20998	-38795	-68555	-1E+05
		Dpsi			0.3497	-48.30	-160.8	-382.8	-791.5	-1481.	-2577.	-4250.	-6668.	-10012	-14417	-20147
(6.145)one447	D2	A			54.849	98.863	163.31	219.41	273.64	327.47	381.22	434.98	488.76	542.83	597.13	651.54
		B			74.168	473.02	1033.3	1827.7	2910.2	4332.1	6000.3	8072.5	10628.	13887.	18082.	23593.
		C			23.019	406.96	1163.0	2577.1	4926.8	8542.3	13550.	20447.	29740.	42377.	59689.	83516.
		D			5.2962	ERR	ERR	7913.4	19497.	41723.	78546.	137771	229797	372201	592935	933685

Table C.6.3 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: CRUISE #2 (M = 0.4, W = 20,932 #, h = 5,000 ft

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			8.4759	-135.5	-293.0	-511.6	-823.0	-1263.	-1856.	-2620.	-3590.	-4785.	-6262.	-8037.
(6.84)one449		A,B,C,D,E>0			YES	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.2018	0.3948	0.5686	0.7093	0.7957	0.7877	0.5740	ERR	ERR	ERR	ERR	ERR

Table C.6.4 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-IN (M = 0.55, W = 39,508 #, h = 1,000 ft)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			24.850	227.60	300.52	202.20	-90.40	-633.4	-1506.	-2812.	-4691.	-7220.	-10607	-15220
		CB			231.85	592.10	1548.1	2530.0	2849.2	1105.8	-5298.	-20325	-50231	-1E+05	-2E+05	-3E+05
		DB			-220.2	-59.72	187.83	643.58	1393.8	2553.0	4265.0	6721.7	10169.	14964.	21636.	30928.
(6.146)one447	NB	AB			0.7380	2.9978	7.7593	14.103	22.091	31.846	43.450	56.967	72.460	90.029	109.73	131.62
rudder		BB			-9.718	115.88	486.37	1179.9	2306.6	3992.4	6352.8	9535.5	13692.	19022.	25742.	34118.
		CB			-88.19	379.18	2547.2	8467.0	21357.	46087.	87217.	154058	258497	420699	670043	1E+06
		DB			87.182	-209.5	-489.5	-824.3	-1274.	-1883.	-2690.	-3735.	-5057.	-6686.	-8656.	-11013
(6.148)one448	Ntheta	Atheta			34.997	504.45	2145.6	5294.0	10542.	18649.	30556.	47466.	70982.	103392	147904	209255
aileron		Btheta			-379.8	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-117.3	645.33	7212.6	32483.	101756	261160	586186	1E+06	2E+06	4E+06	7E+06	1E+07
(6.148)one448	Ntheta	Atheta			-7.949	-53.89	-51.48	16.139	159.43	395.63	744.54	1227.2	1865.6	2649.6	3591.0	4715.2
rudder		Btheta			148.76	-732.9	-2568.	-5764.	-11134	-19744	-32906	-52200	-79515	-1E+05	-2E+05	-2E+05
		Ctheta			37.879	-305.1	-1632.	-4947.	-12138	-26160	-51497	-94852	-2E+05	-3E+05	-4E+05	-6E+05
(6.150)one448	Npsi	Apsi			-24.34	-226.9	-300.5	-204.5	83.730	619.69	1481.5	2771.9	4628.1	7126.2	10472.	15029.
aileron		Bpsi			-212.7	-465.0	-1172.	-1809.	-1648.	772.62	8139.7	24540.	56416.	113111	209064	366438
		Cpsi			-6.546	-20.58	-81.74	-194.7	-303.6	-193.1	691.27	3438.4	10072.	24116.	51496.	102124
		Dpsi			-61.17	192.03	1392.7	4686.3	11729.	25074.	48227.	85886.	145019	235669	373938	582112
(6.150)one448	Npsi	Apsi			11.479	-99.81	-437.3	-1067.	-2083.	-3593.	-5705.	-8534.	-12195	-16825	-22553	-29508
rudder		Bpsi			82.353	-401.6	-2609.	-8636.	-21756	-46912	-88762	-2E+05	-3E+05	-4E+05	-7E+05	-1E+06
		Cpsi			-0.134	-4.457	-47.98	-224.5	-741.3	-1965.	-4424.	-9162.	-17693	-32654	-57651	-99478
		Dpsi			22.118	-85.23	-304.6	-692.6	-1359.	-2441.	-4119.	-6639.	-10232	-15168	-21636	-30007
(6.145)one447	D2	A			46.875	95.072	163.68	222.45	277.67	332.01	386.16	440.30	494.46	548.90	603.57	658.36
		B			124.46	561.08	1166.6	2019.8	3181.2	4706.1	6494.1	8713.8	11450.	14935.	19420.	25310.
		C			-54.14	606.78	1637.8	3487.0	6533.0	11204.	17663.	26544.	38491.	54707.	76888.	107377
		D			-106.0	ERR	ERR	11344.	27909.	59574.	111939	196083	326755	528831	841814	1E+06

Table C.6.4 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-IN (M = 0.55, W = 39,508 #, h = 1,000 ft)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			179.73	-238.1	-555.9	-931.2	-1425.	-2099.	-2988.	-4117.	-5538.	-7279.	-9422.	-11992
(6.84)one449		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.3974	0.7920	1.1807	1.5596	1.9238	2.2662	2.5766	2.8399	3.0416	3.1244	3.0210	2.5823

Table C.6.5 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: MANEUVER (W = 30,220 #, n = 5, h = 1,000 ft, M = 0.35)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			306.86	453.19	590.53	604.22	451.37	76.099	-593.7	-1651.	-3221.	-5348.	-8203.	-12105
		CB			14379.	4820.1	5203.4	7100.2	9444.6	10860.	8620.6	-613.7	-22475	-64832	-1E+05	-3E+05
		DB			-4289.	-2118.	-1465.	-749.3	119.35	1302.4	2965.8	5307.4	8568.9	13098.	19402.	28185.
(6.146)one447	NB	AB			1.0128	4.0377	10.226	18.443	28.866	41.631	56.828	74.538	94.840	117.86	143.70	172.39
rudder		BB			34.717	195.86	533.52	1183.1	2264.8	3902.1	6203.8	9321.9	13412.	18692.	25401.	33844.
		CB			-520.7	1788.3	4175.0	9912.6	22373.	46323.	86198.	151055	252454	410025	652376	1E+06
		DB			153.00	-876.4	-1657.	-2402.	-3253.	-4274.	-5512.	-7011.	-8819.	-10978	-13535	-16553
(6.148)one448	Ntheta	Atheta			-44.07	689.43	2309.9	5485.9	10869.	19242.	31578.	49128.	73559.	107256	153556	217390
aileron		Btheta			-7419.	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-1969.	-2985.	239.52	20962.	83165.	231227	537892	1E+06	2E+06	4E+06	7E+06	1E+07
(6.148)one448	Ntheta	Atheta			-13.27	-31.35	0.1491	101.99	291.05	589.35	1020.6	1609.7	2382.7	3336.0	4486.4	5863.6
rudder		Btheta			257.97	-3083.	-8745.	-16901	-28606	-45087	-67812	-98558	-1E+05	-2E+05	-3E+05	-3E+05
		Ctheta			64.519	-1500.	-6367.	-16342	-34577	-65257	-1E+05	-2E+05	-3E+05	-5E+05	-7E+05	-1E+06
(6.150)one448	Npsi	Apsi			-305.8	-456.3	-597.9	-617.8	-474.3	-112.9	536.79	1566.3	3097.5	5171.9	7956.8	11762.
aileron		Bpsi			-14450	-4768.	-4910.	-6499.	-8413.	-9207.	-6053.	4526.3	28372.	73617.	152917	285298
		Cpsi			-542.4	-353.2	-520.1	-935.3	-1619.	-2419.	-2700.	-1332.	3946.0	17028.	44520.	97343.
		Dpsi			-980.0	-722.8	207.24	3191.7	9760.7	22378.	44429.	80444.	137186	224383	357668	558606
(6.150)one448	Npsi	Apsi			3.8036	-105.5	-418.3	-1000.	-1946.	-3355.	-5328.	-7971.	-11394	-15724	-21085	-27597
rudder		Bpsi			510.15	-1837.	-4339.	-10308	-23196	-47872	-88909	-2E+05	-3E+05	-4E+05	-7E+05	-1E+06
		Cpsi			-5.743	-24.88	-90.70	-326.4	-1013.	-2642.	-5914.	-12211	-23517	-43282	-76199	-1E+05
		Dpsi			39.242	-418.1	-1182.	-2275.	-3848.	-6049.	-9098.	-13310	-18851	-26155	-35366	-46875
(6.145)one447	D2	A			49.203	97.946	165.01	222.51	277.53	331.98	386.32	440.66	495.03	549.69	604.57	659.58
		B			1884.1	2241.5	1987.3	2431.6	3423.5	4888.6	6672.2	8928.0	11734.	15330.	19973.	26080.
		C			-12.31	2068.8	2638.5	3896.5	6335.7	10329.	16001.	23956.	34822.	49799.	70554.	99400.
		D			-1048.	ERR	ERR	13707.	29293.	59226.	108850	188787	313292	506387	806435	1E+06

Table C.6.5 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: MANEUVER (W = 30,220 #, n = 5, h = 1,000 ft, M = 0.35)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			369.93	-980.1	-1839.	-2657.	-3572.	-4687.	-6036.	-7629.	-9551.	-11830	-14595	-17873
(6.84)one449		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			NO	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.3270	0.6493	0.9616	1.2574	1.5281	1.7613	1.9387	2.0295	1.9933	1.6751	0.2221	ERR

Table C.6.6 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-OUT (W = 20,932 #, h = 1,000 ft, M = 0.55)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			57.855	138.30	130.26	-6.092	-307.7	-830.7	-1646.	-2849.	-4561.	-6813.	-9766.	-13731
		CB			85.514	438.90	1052.9	1595.1	1380.5	-992.3	-8037.	-23684	-54078	-1E+05	-2E+05	-4E+05
		DB			-67.58	34.717	247.51	652.11	1336.4	2404.8	3989.2	6267.6	9467.9	13922.	20122.	28760.
(6.146)one447	NB	AB			1.5476	6.1524	14.879	26.615	41.628	60.064	82.036	107.65	137.02	170.34	207.74	249.27
rudder		BB			9.1138	139.05	491.51	1160.3	2267.5	3945.5	6302.1	9507.4	13734.	19240.	26316.	35356.
		CB			3.5189	442.33	2475.6	7990.9	20097.	43427.	82326.	145645	244690	398681	635611	1E+06
		DB			-17.86	-146.2	-315.6	-563.3	-929.4	-1447.	-2153.	-3080.	-4268.	-5742.	-7532.	-9681.
(6.148)one448	Ntheta	Atheta			37.076	630.52	2354.2	5692.8	11331.	20090.	32987.	51330.	76860.	112064	160426	227094
aileron		Btheta			-114.9	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-12.19	824.53	7153.2	30973.	96375.	247204	555229	1E+06	2E+06	4E+06	7E+06	1E+07
(6.148)one448	Ntheta	Atheta			-12.71	-8.666	48.482	181.65	414.37	772.91	1284.8	1978.6	2884.4	4005.0	5362.4	6990.1
rudder		Btheta			-31.96	-517.6	-1674.	-3981.	-8205.	-15334	-26599	-43489	-67785	-1E+05	-1E+05	-2E+05
		Ctheta			-5.732	-222.8	-1098.	-3541.	-9291.	-21090	-43143	-81771	-1E+05	-2E+05	-4E+05	-6E+05
(6.150)one448	Npsi	Apsi			-57.41	-138.6	-133.8	-4.400	285.00	788.50	1575.4	2735.4	4388.4	6559.0	9401.8	13215.
aileron		Bpsi			-70.12	-276.4	-634.5	-800.0	-27.97	3170.1	11442.	28914.	62026.	120159	217789	377196
		Cpsi			-3.605	-23.31	-96.49	-222.0	-275.3	174.11	2179.9	7829.3	20962.	48273.	101001	197976
		Dpsi			-3.589	240.40	1373.0	4448.1	11061.	23634.	45488.	81067.	136967	222710	353587	550700
(6.150)one448	Npsi	Apsi			-5.536	-109.8	-396.9	-936.2	-1817.	-3134.	-4981.	-7456.	-10664	-14725	-19755	-25868
rudder		Bpsi			-11.06	-461.8	-2563.	-8266.	-20777	-44862	-85039	-2E+05	-3E+05	-4E+05	-7E+05	-1E+06
		Cpsi			-0.205	-9.717	-90.63	-409.9	-1344.	-3563.	-8026.	-16643	-32183	-59474	-1E+05	-2E+05
		Dpsi			-2.763	-60.69	-199.4	-482.1	-1011.	-1914.	-3356.	-5565.	-8771.	-13208	-19061	-26682
(6.145)one447	D2	A			52.075	103.37	166.30	222.42	277.22	331.77	386.28	440.83	495.40	550.26	605.36	660.57
		B			133.95	544.13	1187.8	2106.2	3359.8	5007.0	6940.3	9341.7	12304.	16080.	20942.	27330.
		C			69.723	500.62	1444.7	3226.8	6198.3	10779.	17125.	25881.	37702.	53825.	75983.	106603
		D			24.593	ERR	ERR	10570.	26088.	55900.	105325	184856	308470	499805	796435	1E+06

Table C.6.6 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: DASH-OUT (W = 20,932 #, h = 1,000 ft, M = 0.55)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			-11.81	-167.6	-356.9	-632.6	-1032.	-1603.	-2376.	-3375.	-4646.	-6213.	-8152.	-10483
(6.84)one449		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			YES	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.2173	0.4250	0.6121	0.7637	0.8567	0.8481	0.6180	ERR	ERR	ERR	ERR	ERR

Table C.6.7 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: LANDING (W = 20,932 #, h = SEALEVEL, M = 0.15)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
(6.146)one447	NB	AB			0	0	0	0	0	0	0	0	0	0	0	0
aileron		BB			54.981	113.52	62.112	-134.3	-527.0	-1184.	-2192.	-3663.	-5744.	-8522.	-12219	-17228
		CB			91.292	469.85	1078.5	1595.5	1263.5	-1459.	-9331.	-26668	-60214	-1E+05	-2E+05	-4E+05
		DB			-67.46	42.924	275.09	715.69	1462.3	2629.0	4359.9	6849.2	10346.	15213.	21989.	31427.
(6.146)one447	NB	AB			1.5802	6.6450	15.482	27.510	42.966	61.974	84.640	111.07	141.38	175.77	214.36	257.21
rudder		BB			9.7948	157.91	547.35	1290.9	2524.1	4392.1	7016.9	10582.	15275.	21366.	29160.	39062.
		CB			5.2225	505.38	2728.6	8759.1	22010.	47564.	90183.	159572	268129	436921	696635	1E+06
		DB			-21.76	-163.2	-340.5	-606.9	-1003.	-1567.	-2334.	-3345.	-4640.	-6246.	-8199.	-10542
(6.148)one448	Ntheta	Atheta			43.304	641.67	2281.8	5466.0	10852.	19225.	31555.	49093.	73504.	107174	153436	217217
aileron		Btheta			-114.7	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
		Ctheta			-10.08	954.66	7942.9	34144.	106076	271988	610861	1E+06	2E+06	4E+06	7E+06	1E+07
(6.148)one448	Ntheta	Atheta			-14.41	-20.12	17.241	113.50	286.98	558.08	948.17	1479.5	2175.4	3026.7	4046.6	5261.4
rudder		Btheta			-39.03	-578.7	-1810.	-4298.	-8879.	-16634	-28909	-47336	-73863	-1E+05	-2E+05	-2E+05
		Ctheta			-7.329	-250.8	-1196.	-3850.	-10127	-23038	-47209	-89595	-2E+05	-3E+05	-4E+05	-6E+05
(6.150)one448	Npsi	Apsi			-54.44	-113.4	-64.37	126.74	509.86	1151.9	2137.2	3574.3	5608.0	8321.6	11933.	16824.
aileron		Bpsi			-72.47	-303.3	-666.8	-810.7	89.014	3673.9	12856.	32179.	68725.	132834	240442	416075
		Cpsi			-3.798	-26.90	-107.7	-246.0	-299.8	219.74	2507.2	8930.2	23842.	54837.	114654	224647
		Dpsi			-2.234	277.16	1518.8	4885.4	12129.	25907.	49862.	88865.	150151	244157	387646	603753
(6.150)one448	Npsi	Apsi			-5.636	-128.5	-454.5	-1071.	-2084.	-3598.	-5724.	-8575.	-12270	-16946	-22735	-29767
rudder		Bpsi			-13.73	-530.0	-2828.	-9065.	-22761	-49146	-93177	-2E+05	-3E+05	-5E+05	-7E+05	-1E+06
		Cpsi			-0.228	-11.56	-103.6	-465.1	-1523.	-4035.	-9089.	-18848	-36450	-67363	-1E+05	-2E+05
		Dpsi			-3.614	-67.99	-216.1	-521.6	-1097.	-2080.	-3654.	-6067.	-9570.	-14423	-20824	-29161
(6.145)one447	D2	A			51.455	108.04	167.45	222.48	276.89	331.26	385.68	440.14	494.65	549.46	604.49	659.62
		B			150.35	539.70	1150.0	2032.8	3240.7	4827.6	6690.0	9001.7	11850.	15478.	20144.	26267.
		C			80.841	550.56	1574.6	3526.2	6786.1	11812.	18778.	28379.	41326.	58948.	83116.	116434
		D			30.982	ERR	ERR	11568.	28553.	61207.	115366	202538	338054	547831	873068	1E+06

Table C.6.7 LATERAL-DIRECTIONAL AIRPLANE TRANSFER FUNCTIONS
FLIGHT CONDITION: LANDING (W = 20,932 #, h = SEALEVEL, M = 0.15)

Reference	Unit	Variable	Given	Measu	M=.05	M=.10	M=.15	M=.20	M=.25	M=.30	M=.35	M=.40	M=.45	M=.50	M=.55	M=.60
		E			-16.93	-187.0	-385.1	-681.3	-1114.	-1734.	-2576.	-3664.	-5049.	-6759.	-8873.	-11415
(6.84)one449		A,B,C,D,E>0			NO	ERR	ERR	NO	NO	NO	NO	NO	NO	NO	NO	NO
		D(BC-AD)-B2E>0			YES	ERR	ERR	YES	YES	YES	YES	YES	YES	YES	YES	YES
(6.104)one427	r/s	Wn S.P.			0.2043	0.3997	0.5757	0.7183	0.8057	0.7976	0.5812	ERR	ERR	ERR	ERR	ERR

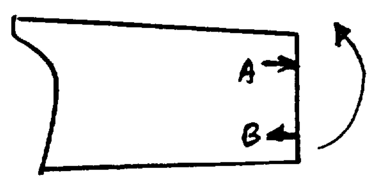
APPENDIX D

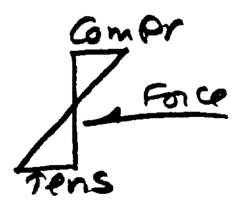
The purpose of this appendix is to show the calculations for the wing component sizing and the flutter analysis. Also presented is the method used for the flutter analysis, which was formulated by Dr. James Locke of the University of Kansas.

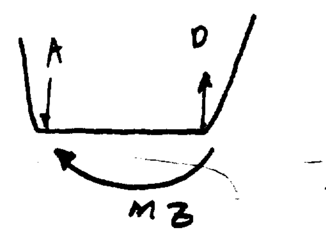
Table of Contents

Purpose: Size spar caps & stringers so that All members take load.

Item	Location: (Frac of c) (rel to Elastic Axis) x	z
A	(.25 ,	.067)
B	(.25 ,	-.051)
C	(-.245 ,	.045)
D	(-.245 ,	-.025)
a	(.15 ,	.082)
b	(.05 ,	.084)
c	(-.05 ,	.078)
d	(-.15 ,	.065)
e	(.15 ,	-.062)
f	(.05 ,	-.063)
g	(-.05 ,	-.056)
h	(-.15 ,	-.044)







$$.067c\,F_A + .051c\,F_B + .045c\,F_C + .025c\,F_D + .082c\,F_a + .084c\,F_b + .078c\,F_c + .065c\,F_d + .062c\,F_e + .063c\,F_f + .056c\,F_g + .044c\,F_h = M_x$$

$F_B = (.051/.067)F_A = .761\,F_A$ (Tension)
$F_C = (.045/.067)F_A = .672\,F_A$ (Compr)
$F_D = (.025/.067)F_A = .373\,F_A$ (Tens)
$F_a = (.082/.067)F_A = 1.224\,F_A$ (Compr)
$F_b = (.084/.067)F_A = 1.254\,F_A$
$F_c = (.078/.067)F_A = 1.164\,F_A$
$F_d = (.065/.067)F_A = .970\,F_A$ (compr)
$F_e = (.062/.067)F_A = .925\,F_A$ (Tens)
$F_f = (.063/.067)F_A = .940\,F_A$
$F_g = (.056/.067)F_A = .836\,F_A$
$F_h = (.044/.067)F_A = .657\,F_A$

$$(.067c + .039c + .030c + .009c + .100c + .105c + .091c + .063c + .057c + .059c + .047c + .029c)FA = M_x$$

$$.696cFA = M_x$$

	M_x	M_z	c
ROOT:	29,968 kip·in	-4,513 kip·in	187.2"
B.L. 240	7,954 kip·in	-1,192 kip·in	128.4"
B.L. 360	1,881 kip·in	-269 kip·in	104.4"

LOADS DUE TO Bending moments: (kips)

	ROOT	240	360	
FA	230	89	26	C
FB	175	68	19.7	T
FC	155	60	17	C
FD	86	33	10	T
Fa	282	109	32	C
Fb	288	112	33	C
Fc	268	104	30	C
Fd	223	86	25	C
Fe	213	82	16	T
Ff	216	84	24	T
Fg	192	74	22	T
Fh	151	58	17	T

$$.25cFA + .25cFB + .245cFC + .245cFD + .15cFa + .05cFb + .05cFc + .15cFd + .15cFe + .05cFf + .05cFg + .15cFh = M_z$$

FB =	FA	= FA	C
FC =	.245/.25 FA	= .98 FA	T
FD =	.245/.25 FA	= .98 FA	T
Fa =	.15/.25 FA	= .60 FA	C
Fb =	.05/.25 FA	= .20 FA	C
Fc =	.05/.25 FA	= .20 FA	T
Fd =	.15/.25 FA	= .60 FA	T
Fe =	.15/.25 FA	= .60 FA	C
Ff =	.05/.25 FA	= .20 FA	C
Fg =	.05/.25 FA	= .20 FA	T
Fh =	.15/.25 FA	= .60 FA	T

$$(.25c + .25c + .24c + .24c + .09c + .010c$$
$$+ .010c + .09c + .09c + .010c + .010c + .090c)FA = M_z$$

$$1.38_c FA = -M_z$$

LOADS DUE TO Z-AXIS MOMENTS: (KIPS)

		ROOT	240	360	
FA	+	17.5	6.7	1.9	C
FB	-	17.5	6.7	1.9	C
FC	-	17.2	6.6	1.9	T
FD	+	17.2	6.6	1.9	T
Fa	+	10.5	4.0	1.1	C
Fb	+	3.5	1.3	.4	C
Fc	-	3.5	1.3	.4	T
Fd	-	10.5	4.0	1.1	T
Fe	-	10.5	4.0	1.1	C
Ff	-	3.5	1.3	.4	C
Fg	+	3.5	1.3	.4	T
Fh	+	10.5	4.0	1.1	T

TOTAL LOADS ON MEMBERS (KIPS)

	ROOT	240	360	
FA	247.5	95.7	27.9	C
FB	157.5	61.3	17.8	T
FC	137.8	53.4	15.1	C
FD	103.2	39.6	11.9	T
Fa	292.5	113.0	33.1	C
Fb	291.5	113.3	33.4	C
Fc	264.5	102.7	29.6	C
Fd	212.5	82.0	23.9	C
Fe	202.5	78.0	14.9	T
Ff	212.5	82.7	23.6	T
Fg	195.5	75.3	22.4	T
Fh	161.5	62.0	18.1	T

Paul Darrah | Spar Sizing | 3/26/84 | 4

MATerial: Metal-MATRIX composite of (EXTRUSION) Al-2024 with 20% silicon Carbide

Ref: Aerospace America, MARCH 1989 "New Life for Aluminum" - R. DeMeis.

25% Improvement in Strength at Constant Density.

ASSUME No Buckling of Skin.

MATERIAL Properties (Smith's Materials Book) : AL-2024

		+15% Safety margin:
Tensile yield:	47 ksi	40.9 ksi
Compressive yield:	45 ksi	39.1 ksi

15% safety margin is used to Allow for The fact That This Analysis was done for one Fc only.

Metal-MATRIX:

Use: Tensile yield (incl. 15% S.M.) = 54.5 ksi
Compressive yield (incl. 15% S.M.) = 52.1 ksi

AREAS OF MEMBERS (in^2)

	ROOT	240	360	TIP (ARBITRARY)
A	4.75	1.84	.54	.18
B	2.89	1.12	.33	.11
C	2.64	1.02	.29	.10
D	1.89	.73	.22	.07
a	5.61	2.17	.64	.22
b	5.60	2.17	.64	.22
c	5.08	1.97	.57	.20
d	4.08	1.57	.46	.16
e	3.72	1.43	.27	.14
f	3.90	1.52	.43	.15
g	3.59	1.38	.41	.14
h	2.96	1.14	.33	.11
Σ	46.71	18.06	5.13	1.81
WT (lb)	641 lb	139 lb	49 lb	TOTAL: 829 lb

ROOT Area = 196.46 TOTAL. 1025

D4

TOTAL Wing Spar & Stringer Weight = 829 lb
with Conventional Al-2024 = 1105 lb

WT SAVINGS = 276 lb

$A_A = A_A$
$A_B = .61\,A_A$
$A_C = .56\,A_A$
$A_D = .40\,A_A$
$A_a = 1.18\,A_A$
$A_b = 1.19\,A_A$
$A_c = 1.07\,A_A$
$A_d = .86\,A_A$
$A_e = .78\,A_A$
$A_f = .82\,A_A$
$A_g = .76\,A_A$
$A_h = .62\,A_A$

$I_x = \Sigma A(z^2)$

$.0045c^2A_A + .0026c^2A_B + .0020c^2A_C + .0006c^2A_D + .0067c^2A_a + .0071c^2A_b + .0061c^2A_c + .0042c^2A_d + .0038c^2A_e + .0040c^2A_f + .0031c^2A_g + .0019c^2A_h = I_x$

$A_Ac^2(.0045 + .0016 + .0011 + .0002 + .0079 + .0084 + .0065 + .0036 + .0030 + .0033 + .0024 + .0012) = I_x$

$.0437\,A_Ac^2 = I_x$

$I_z = \Sigma A(x^2)$

$.0625c^2A_A + .0625c^2A_B + .06c^2A_C + .06c^2A_D + .0225A_ac^2 + .0025A_bc^2 + .0025A_cc^2 + .0225A_dc^2 + .0225A_ec^2 + .0025A_fc^2 + .0025A_gc^2 + .0225A_hc^2$

$A_Ac^2(.0625 + .0381 + .0336 + .024 + .0266 + .003 + .0027 + .0194 + .0176 + .0021 + .0019 + .014) = I_z$

$.2455\,c^2A_A = I_z$

$I_{xz} = \Sigma A(z)(x)$

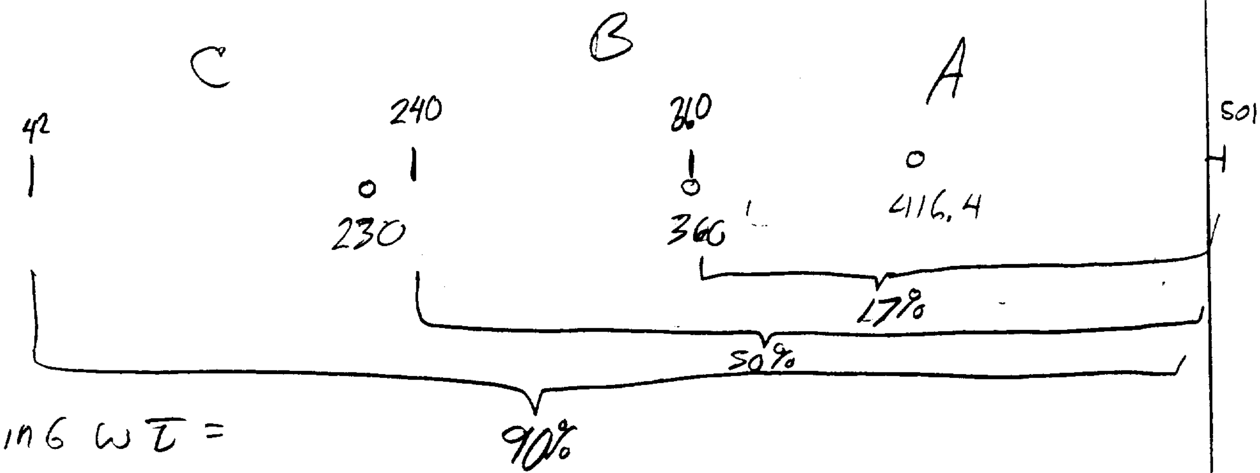
$.0168 A_A c^2 - .0128 A_B c^2 - .0110 A_C c^2 + .0061 A_D c^2$
$+ .0123 A_a c^2 + .004 A_b c^2 - .0039 A_c c^2 - .0098 A_d c^2$
$- .0098 A_e c^2 - .0032 A_f c^2 + .0028 A_g c^2 + .0066 A_h c^2$

$A_A c^2 (.0168 - .0078 - .0062 + .0024$
$+ .0145 + .0047 - .0042 - .0084$
$- .0076 - .0026 + .0021 + .0041) = I_{xz}$

$.0078 A_A c^2 = I_{xz}$

	ROOT	240	360	TIP
I_x	7,274 in^4	1,326 in^4	257 in^4	25 in^4
I_z	40,865 in^4	7,447 in^4	1,445 in^4	143 in^4
I_{xz}	1,298 in^4	237 in^4	46 in^4	4.5 in^4

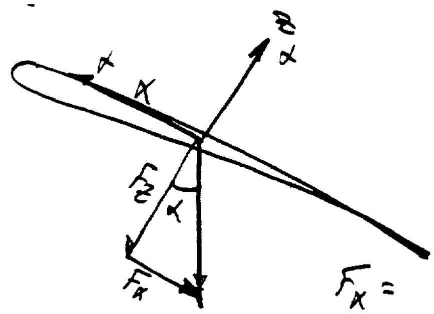
Note: Tip chord (B.L. 501 - Does not include the Tip fairing)
= 56.88"



WING WT =

SECTION:	WT	F
A	448 lb	4861 lb
B	1,320 lb	14,296 lb
C	2,376 lb	25,732 lb

		M_z (in·lb)	M_x (in·lb)	F_x (lb)	F_z (lb)
M_{360}	= 274,160	57,001	-268,169	1,011	4,755
M_{240}	= 1,715,520	356,677	-1,678,032	2,972	13,984
M_{ROOT}	= 4,837,616	1,005,797	-4,731,902	5,380	25,170



$\alpha = 12°$

$F_x = F \sin 12°$

$F_z = F \cos 12°$

FROM Previous work

$.696\,c\,FA = M_x$ 〉 Before combining

$1.38\,c\,FA = -M_z$

Accounting for inertial Relief,

B.L.	M_x (Kip·in)	M_z (Kip·in)
Root	25,236	-3,507
240	6,276	-835
360	1,612	-212

The Spar sizes due to each load are thus related to those without inertial relief in the following manner

Bl.	M_{xir}/M_{xnir}	M_{zir}/M_{znir}
Root	.84	.78
240	.79	.70
360	.86	.78

M_{zir} = M_z with Inertial Relief

M_{znir} = M_z, no Inertial relief.

These numbers are inconsistent, so assume that $M_{xir}/M_{xnir} = .85$ and

$M_{zir}/M_{znir} = .78$

Thus, due to M_x (Kips)

	Root	240	360	
FA	196	76	22	C
FB	149	58	17	T
FC	132	51	14	C
FD	73	28	9	T
Fa	240	93	27	C
Fb	245	95	28	C
Fc	228	88	26	C
Fd	190	73	21	C
Fe	181	70	14	T
Ff	184	71	20	T
Fg	163	63	19	T
Fh	128	49	14	T

Due to Z-Axis moments (Kips)

	Root	240	360	
FA	13.65	5.23	1.48	C
FB	13.65	5.23	1.48	C
FC	13.42	5.15	1.48	T
FD	13.42	5.15	1.48	T
Fa	8.19	3.12	.86	C
Fb	2.73	1.01	.31	C
Fc	2.73	1.01	.31	T
Fd	8.19	3.12	.86	T
Fe	8.19	3.12	.86	C
Ff	2.73	1.01	.31	C
Fg	2.73	1.01	.31	T
Fh	8.19	3.12	.86	T

For items where the loads add,

$$\frac{\text{Load with inertial relief}}{\text{Load without}} = .85$$

For items where the loads subtract, this is: .86

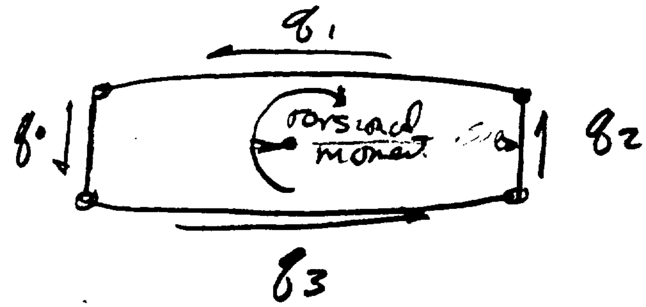
AREA (in^2)

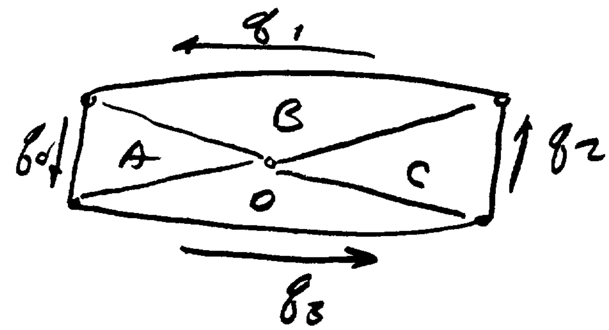
Item	Root	240	360	501
A +	4.04	1.56	.46	.16
B -	2.49	.96	.29	.10
C -	2.27	.88	.25	.09
D +	1.61	.62	.19	.06
a +	4.77	1.84	.53	.18
b +	4.76	1.84	.53	.18
c -	4.37	1.69	.49	.17
d -	3.51	1.35	.40	.14
e -	3.20	1.23	.23	.12
f -	3.35	1.31	.37	.13
g +	3.05	1.17	.35	.12
h +	2.52	.97	.28	.10
Σ	39.94	15.42	4.37	1.55

wt (lb) 548 119. 43.6

TOTAL: 711 lb

Inertial relief saves: 14.5%

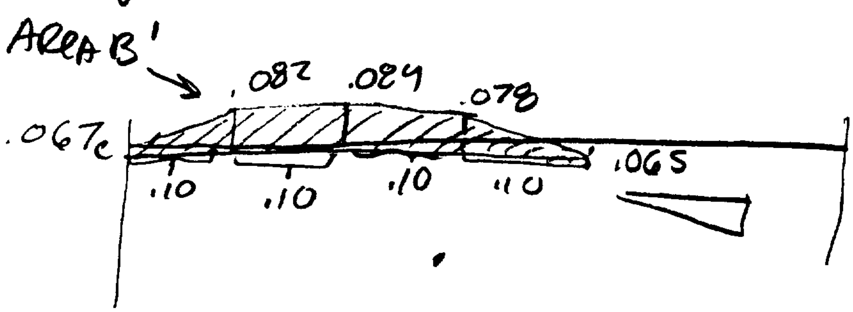




$$q_0 A2 + q_2 C2 + q_1 B2 + q_3 D2 = TM$$

$$q_0 = q_2 = q_1 = q_3$$

To find Area B:



AREA B' =

$$\left(\frac{.078_c - .065_c}{2}\right)(.10_c) + (.078_c)(.10c) + \left(\frac{.084_c - .078c}{2}\right)(.10c)$$
$$+ (.082)(.10) + \left(\frac{.084_c - .082_c}{2}\right)(.10c) + (.067 - .065_c)(.10_c)$$
$$+ \left(\frac{.082c - .067c}{2}\right)(.10c) = .018\, c^2$$

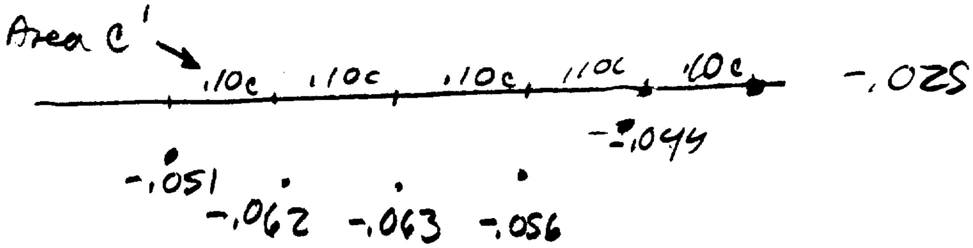
$$\text{Thus Area B} = ((.065(.5)) + .018)c^2 = .0505\, c^2$$

$$\left(-\frac{.065 + .045}{2}\right).10$$

$$= .0495\, c^2$$

Paul Danah

To find Area C.



$$(.051c)(.10c) + \left(\frac{.062-.051}{2}\right)(.10c) + (.062)(.10c) + \left(\frac{.063-.062}{2}\right)c^2(.1)$$

$$+ (.056)(.10c^2) + \left(\frac{.063-.056}{2}\right)(.10c^2) + (.044)c^2 .10$$

$$+ \left(\frac{.056-.044}{2}\right)c^2(.10) + \left(\frac{.044-.025}{2}\right)(.10c^2)$$

$$c' = .0238c^2$$

$$C = .0238c^2 + (.025)(.5)c^2 = .0363c^2$$

$$\text{Area } A = \left(\frac{.067+.051}{2}\right)(.45c^2) = .0266c^2$$

$$\text{Area } D = \left(\frac{.025+.045}{2}\right)(.55c^2) = .0193c^2$$

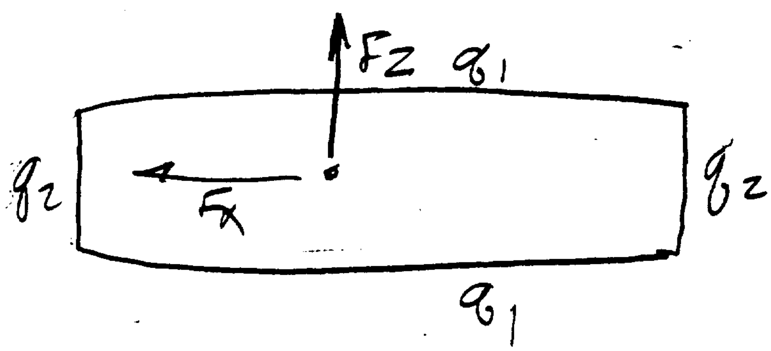
$$q_0(2(.0266c^2) + 2(.093c^2) + 2(.0495c^2) + 2(.0238c^2))$$
$$= TM$$

$$.2634c^2 q_0 = TM$$

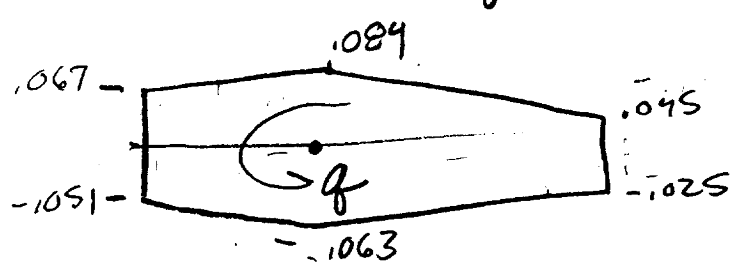
Paul Damek

B. L.	T. M	c	q_0
Root	4,712 kip·in	187.2"	.5104 kip/in
240	4,415 kip·in	128.4"	1.02 kip/in
360	2,530 kip·in	109.4"	.88 kip/in

Added to torsion is normal load.



Approximate Torque Box:

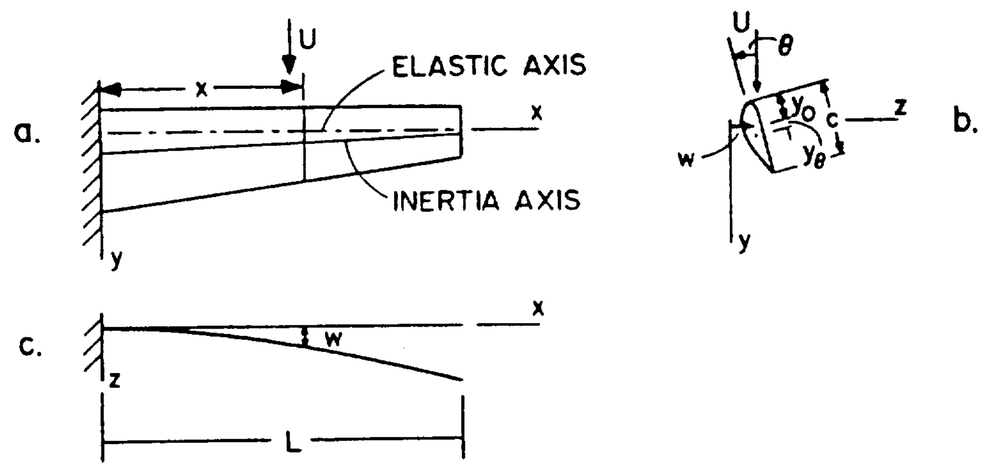


$F_z = ((.045+.025)+(.067+.051))cq_2 + (.084-.067 + .063-.051)cq_1$

$F_z = .188cq_2 + .029cq_1$

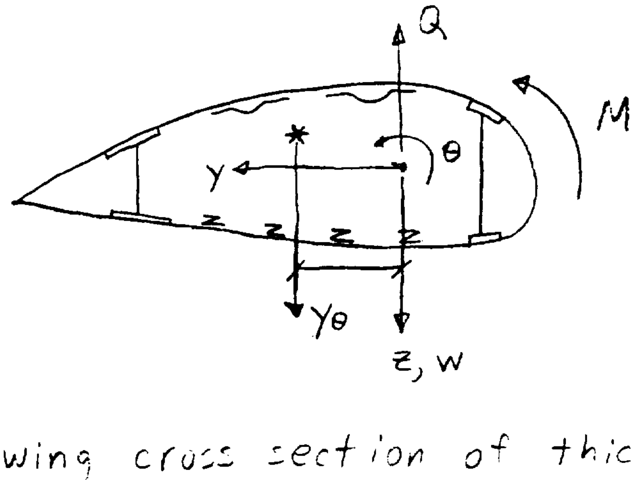
$F_x = .\ q_1 c$

Flutter of cantilever aircraft wing J. Locke



$w(x,t)$ bending deflection of elastic axis
$\theta(x,t)$ torsional rotation about elastic axis

$Q(x,t)$ vertical wing loading
$M(x,t)$ twisting moment loading



* inertia axis or mass center (IA)

• elastic axis (EA)

y_θ distance between IA & EA

wing cross section of thickness dx

The vertical velocity of any point on the wing cross section is

$$v(x,t) = \dot{w}(x,t) + y\,\dot{\theta}(x,t)$$

The kinetic energy for a thickness dx is

$$dT = \int_A \left(\tfrac{1}{2}\rho v^2\right) dA$$

A - cross sectional wing area

ρ - mass density

$$dT = \int_A \tfrac{1}{2}\rho(\dot{w} + y\dot{\theta})^2 \, dA$$

$$= \tfrac{1}{2}\dot{w}^2 \underbrace{\int_A \rho \, dA}_{m} + \tfrac{1}{2}\dot{\theta}^2 \underbrace{\int_A y^2 \rho \, dA}_{I_\theta} + \dot{w}\dot{\theta}\underbrace{\int_A y\rho \, dA}_{y_\theta m} \, .$$

m - mass density per unit length of wing

I_θ - mass moment of inertia of wing about EA

The total kinetic energy for the wing is

$$T = \int_0^L dT = \tfrac{1}{2}\int_0^L (m\dot{w}^2 + I_\theta\dot{\theta}^2 + 2y_\theta m\dot{w}\dot{\theta})\, dx \, . \qquad (1)$$

The bending strain energy is

$$U_b = \tfrac{1}{2}\int_0^L EI(w_{,xx})^2 \, dx \, , \qquad (2)$$

$$w_{,xx} = \frac{\partial^2 w}{\partial x^2}$$

and the torsional strain energy is

$$U_t = \tfrac{1}{2}\int GJ(\theta_{,x})^2 \, dx \, . \qquad (3)$$

$$\theta_{,x} = \frac{\partial \theta}{\partial x}$$

GJ torsional stiffness, EI bending stiffness

C-4

The wing can be modeled as a two-degree-of-freedom system by assuming the following type of solution

$$w(x,t) = q_1(t)\,\phi(x) = q_1\phi \qquad (4)$$
$$\theta(x,t) = q_2(t)\,\psi(x) = q_2\psi \quad .$$

q_1 & q_2 generalized coordinates
ϕ bending mode shape for cantilever beam
ψ torsional mode shape for cantilever beam

The equations of motion for a system with generalized coordinates can be found using Lagrange's equations

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) + \frac{\partial U}{\partial q_i} = Q_i \quad . \qquad (5)$$

T Kinetic energy
U potential energy
Q_i generalized force for ith degree-of-freed

Substituting Eq. (4) into Eqs. (1)-(3)

$$T = \frac{1}{2}\dot{q}_1^2 \underbrace{\int_0^L m\phi^2\,dx}_{m_{11}} + \frac{1}{2}\dot{q}_2^2 \underbrace{\int_0^L I_\theta \psi^2\,dx}_{m_{22}} + \dot{q}_1\dot{q}_2 \underbrace{\int_0^L y_\theta m \phi\psi\,dx}_{m_{12}}$$

$$= \frac{1}{2}m_{11}\dot{q}_1^2 + \frac{1}{2}m_{22}\dot{q}_2^2 + \dot{q}_1\dot{q}_2\,m_{12} \qquad (6)$$

$$U = \frac{1}{2} q_1^2 \underbrace{\int_0^L EI\Phi_{,xx}^2 \, dx}_{k_{11}} + \frac{1}{2} q_2^2 \underbrace{\int_0^L GJ\Psi_{,x}^2 \, dx}_{k_{22}}$$

$$= \frac{1}{2} k_{11} q_1^2 + \frac{1}{2} k_{22} q_2^2 . \qquad (7)$$

Substituting Eqs. (6) & (7) into Eq. (5), the equations of motion are given by

$$\begin{bmatrix} k_{11} & 0 \\ 0 & k_{22} \end{bmatrix} \begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix} + \begin{bmatrix} m_{11} & m_{12} \\ m_{12} & m_{22} \end{bmatrix} \begin{Bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{Bmatrix} = \begin{Bmatrix} -Q_1 \\ Q_2 \end{Bmatrix}$$

or $\qquad [K]\{q\} + [M]\{\ddot{q}\} = \{Q\}$, $\qquad (8)$

where the generalized forces Q_1 & Q_2 are given by

$$Q_1 = \int_0^L Q \Phi \, dx$$
$$\qquad (9)$$
$$Q_2 = \int_0^L M \Psi \, dx .$$

Both Q & M are functions of x & t, hence Q_1 & Q_2 will be functions of time. Generally speaking, Q & M depend on the <u>speed</u> <u>of</u> the <u>air</u> <u>relative to</u> the <u>wing u</u> as well as $\dot{w}, \dot{\theta}$, & θ & the force matrix can be written in the form

$$\{Q\} = -u^2 [H]\{q\} - u[L]\{\dot{q}\} . \qquad (10)$$

Substituting Eq. (10) into Eq. (8)

$$[K]\{q\} + [M]\{\ddot{q}\} = -u^2[H]\{q\} - u[L]\{\dot{q}\} \quad . \qquad (11)$$

Assuming a time solution of the form

$$\{q\} = \{A\}e^{\lambda t} \Rightarrow \{\dot{q}\} = \lambda\{A\}e^{\lambda t} = \lambda\{q\}$$
$$\{\ddot{q}\} = \lambda^2\{A\}e^{\lambda t} = \lambda^2\{q\} \; ,$$

and substituting into Eq. (11) we obtain

$$\left[[K] + u^2[H] + \lambda u[L] + \lambda^2[M]\right]\{q\} = \{0\} \quad . \qquad (12)$$

The eigenvalue λ is a continuous function of the air speed u. For $u = 0$ the above problem reduces to

$$[K]\{q\} = -\lambda^2[M]\{q\} \; .$$

Since $[K]$ & $[M]$ are positive definite symmetric matrices, $-\lambda^2$ must be real & positive. Hence, $\lambda = \pm i\omega$, indicating free oscillatory vibration with frequency ω. But, when $u \neq 0$ λ is no longer pure imaginary but complex $\lambda = \alpha + i\omega$. For damped stable motion α must be negative. As u increases, α can become positive & the motion is unstable.

When $\alpha = 0$ & $\omega \neq 0$ the wing is said to be in critical flutter condition. The critical flutter speed u_{CR} is the lowest value of u for which $\alpha = 0$.

To compute u_{CR}, $\alpha = 0$. Thus, $\lambda = i\omega$ & substituting into Eq. (12)

$$\underbrace{\left[[K] + u^2[H] + i\omega u[L] - \omega^2[M]\right]}_{[K^*]}\{q\} = \{0\}$$

or $\quad \left|[K^*]\right| = 0$.

Set both the imaginary and real parts of the determinant equal to zero. This will result in two equations with two unknowns ω & u. u_{CR} is the smallest positive value of u.

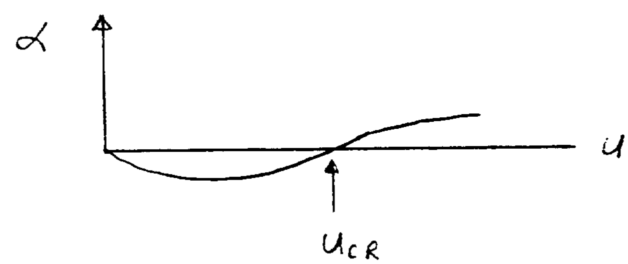
* Alternative solution for u_{CR}

Start with Eq. (12). For a given value of u compute

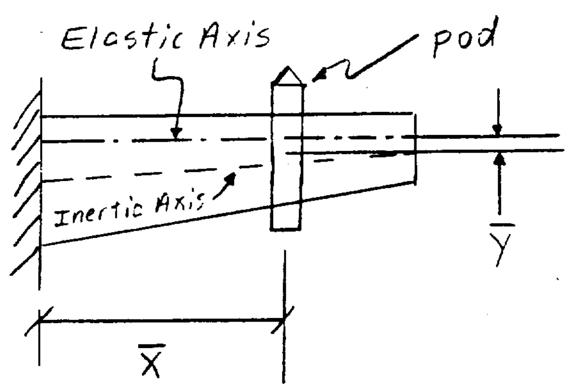
$$\left|\left[[K] + u^2[H] + \lambda u[L] + \lambda^2[M]\right]\right| = 0$$

and solve for $\lambda = \alpha + i\omega$. Start with $u=0$ and increment u gradually. Plot u vs. α.

u_{CR} occurs at $\alpha = 0$.



*Effect of additional masses (i.e., external stores, fuel, etc.)



m_{pod} - total mass of pod

I_{pod} - mass moment of inertia of pod about EA

$\bar{Y}$ - distance between mass center of pod & EA

$$T_{pod} = \frac{1}{2} m_{pod} \dot{w}^2(\bar{x}) + \frac{1}{2} I_{pod} \dot{\theta}^2(\bar{x}) + m_{pod} \bar{y} \dot{w}(\bar{x}) \dot{\theta}(\bar{x})$$

but
$$\dot{w}(\bar{x}) = \dot{q}_1 \phi(\bar{x})$$
$$\dot{\theta}(\bar{x}) = \dot{q}_2 \psi(\bar{x})$$

$$T_{pod} = \frac{1}{2} m_{pod} \phi^2(\bar{x}) \dot{q}_1^2 + \frac{1}{2} I_{pod} \psi^2(\bar{x}) \dot{q}_2^2 + m_{pod} \bar{y} \phi(\bar{x}) \psi(\bar{x}) \dot{q}_1 \dot{q}_2$$

Now the additional terms in the equations of motion can be found by letting $T = T_{pod}$ and using Eq.(5). Note that only the mass matrix [M] will change.

* Beam mode shapes

$$\phi(x) = \cosh\frac{\lambda x}{L} - \cos\frac{\lambda x}{L} - \sigma\left(\sinh\frac{\lambda x}{L} - \sin\frac{\lambda x}{L}\right)$$

$$\lambda = 1.87510407$$
$$\sigma = .734095514$$

$$\psi(x) = \sin\frac{\pi x}{2L}$$

References

1. L. Meirovitch, "Computational Methods in Structural Dynamics"
2. Blevins, "Formulas for Natural Frequency and Mode Shape"

Note: To account for the variation of mass and stiffness along the wing, break the wing up into several pieces and use average values for each segment. For instance, say the wing is divided into 4 pieces of equal length, then

$$\int_0^L m\,\phi^2\,dx \doteq m_1\int_0^{L/4}\phi^2\,dx + m_2\int_{L/4}^{L/2}\phi^2\,dx + m_3\int_{L/2}^{3L/4}\phi^2\,dx + m_4\int_{3L/4}^{L}\phi^2\,dx\,.$$

$m_1 \rightarrow m_4$ are the average mass per unit length for each segment.

Flutter Analysis of the wing (Good Aircraft)

From the formulation of Dr. Locke, University of Kansas:

$$T = \tfrac{1}{2}\,\dot{q}_1^2 \underbrace{\int_0^L m\,\phi^2\,dx}_{m_{11}} + \tfrac{1}{2}\,\dot{q}_2^2 \underbrace{\int_0^L I_\theta\,\Psi^2\,dx}_{m_{22}} + \dot{q}_1\dot{q}_2 \underbrace{\int_0^L y_\theta\,m\,\phi\,\Psi\,dx}_{m_{12} = m_{21}}$$

$$U = \tfrac{1}{2}\,q_1^2 \underbrace{\int_0^L EI\,\phi_{,xx}^2\,dx}_{K_{11}} + \tfrac{1}{2}\,q_2^2 \underbrace{\int_0^L GJ\,\Psi_{,x}^2\,dx}_{K_{22}}$$

where:

$$\phi(x) = \cosh\left(\frac{1.875x}{L}\right) - \cos\left(\frac{1.875x}{L}\right) - .7341\left[\sinh\left(\frac{1.875x}{L}\right) + \right.$$
$$\left. - \sin\left(\frac{1.875x}{L}\right)\right]$$

$$\Psi(x) = \sin\left(\frac{\pi x}{2L}\right)$$

The wing will be broken down into 8 segments and the integrations will be carried out for each of the segments. The segments are:

1	0 - 35	BL
2	35 - 108	
3	108 - 132	
4	132 - 215	
5	215 - 278	
6	278 - 343	
7	343 - 408	
8	408 - 474	

The computer code, MATHCAD, will be used to perform the numerical integration.

In matrix form:

$$\begin{bmatrix} K_{11} & 0 \\ 0 & K_{22} \end{bmatrix} \begin{bmatrix} \xi_1 \\ \xi_2 \end{bmatrix} + \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} \ddot{\xi}_1 \\ \ddot{\xi}_2 \end{bmatrix} = \begin{bmatrix} -Q_1 \\ Q_2 \end{bmatrix} = \underline{Q}$$

where:

$$\underline{Q} = -u^2 [H] \underline{\xi} - u [L] \underline{\dot{\xi}}$$

Q_1 = Generalized Lift

Q_2 = Generalized Moment

$$\text{Total Lift} = \text{Steady State Lift} + \underbrace{\text{Perturbed Lift}}_{Q_1}$$

Q_1 (or the perturbed lift) results from motion induced angle of attack. Let:

$w(x,t)$ = bending deflection of the elastic axis
$\theta(x,t)$ = torsional rotation about the elastic axis

The vertical velocity of some point on the wing cross section (y units from the elastic axis) is:

$$\text{Vertical Velocity} = v = \dot{w} + y\dot{\theta}$$

The induced angle of attack is:

$$\alpha_{induced} = -\frac{v}{U} = \frac{-(\dot{w} + y\dot{\theta})}{U}$$

if v is small compared to U.

$$Q_1 = \bar{q}\ \Delta C_L\ S$$

$$\Delta C_L = C_{L_\alpha}(\alpha_{induced} + \theta) = C_{L_\alpha}\left(-\frac{\dot{w} - y\dot{\theta}}{U} + \theta\right)$$

For a segment of the wing:

$$Q_{1_{segment}} = \bar{q} \int_{x_1}^{x_2} c(x)\, c_{\ell_\alpha}(x) \left[-\frac{\dot{w} - y\dot{\theta}}{U} + \theta\right] dx$$

But:

$$w(x,t) = \phi(x)\, q_1(t) \qquad \Rightarrow \qquad \dot{w} = \frac{dw}{dt} = \phi(x)\, \dot{q}_1(t)$$

$$\theta(x,t) = \Psi(x)\, q_2(t) \qquad\qquad \dot{\theta} = \frac{d\theta}{dt} = \Psi(x)\, \dot{q}_2(t)$$

Substituting into the equation:

$$Q_{1_{segment}} = 1/2\, \rho U^2 \Big[\int_{x_1}^{x_2} c(x)\, c_{\ell_\alpha}(x)\, \Psi(x)\, q_2(t)\, dx \quad +$$

$$- \int_{x_1}^{x_2} c(x)\, c_{\ell_\alpha}(x)\, \frac{\phi(x)\, \dot{q}_1(t)}{U}\, dx - \int_{x_1}^{x_2} c(x)\, c_{\ell_\alpha}(x)\, y \frac{\Psi(x)\, \dot{q}_2(t)}{U}\, dx \Big]$$

Assuming that $c_{\ell_\alpha}(x) = \text{constant} = c_{\ell_\alpha}$

$$Q_{1_{segment}} = 1/2\, \rho U^2 c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, \Psi(x)\, dx \quad q_2(t) \quad +$$

$$- 1/2\, \rho U c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, \phi(x)\, dx \quad \dot{q}_1(t) \quad +$$

$$- 1/2\, \rho U c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, y\, \Psi(x)\, dx \quad \dot{q}_2(t)$$

Using a similar procedure, one can obtain:

$$Q_{2_{segment}} = 1/2\, \rho U^2 C_{m_\alpha} \bar{c} \int_{x_1}^{x_2} c(x)\, \Psi(x)\, dx \quad q_2(t) \quad +$$

$$- 1/2\, \rho U C_{m_\alpha} \bar{c} \int_{x_1}^{x_2} c(x)\, \phi(x)\, dx \quad \dot{q}_1(t) \quad +$$

$$- 1/2\, \rho U C_{m_\alpha} \bar{c} \int_{x_1}^{x_2} c(x)\, y\, \Psi(x)\, dx \quad \dot{q}_2(t)$$

But,

$$M = L \cdot \text{moment arm}$$

$$\bar{q}\, C_m\, \bar{c}\, S = \bar{q}\, C_L\, S \cdot \text{moment arm}$$

$$C_m\, \bar{c} = C_L \cdot \text{moment arm}$$

$$C_{m_\alpha} \bar{c} = C_{L_\alpha} \cdot \text{moment arm}$$

$$C_{m_\alpha} = c_{\ell_\alpha} \cdot \frac{\text{moment arm}}{\bar{c}}$$

The moment arm is the distance from the elastic axis (.46 c) and the aerodynamic center (.25 c). Therefore:

$$\text{moment arm} = (.46 - .25)\,c = .21\,c$$

Note that c is a function of the position along the wing span. Thus:

$$Q_{2_{segment}} = \tfrac{1}{2}\rho U^2 c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, \Psi(x)\, dx\; q_2(t) \;+$$
$$- \tfrac{1}{2}\rho U c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, \phi(x)\, dx\; \dot{q}_1(t) \;+$$
$$- \tfrac{1}{2}\rho U c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, y(x)\Psi(x)\, dx\; \dot{q}_2(t)$$

In matrix form:

$$\begin{bmatrix} -Q_1 \\ Q_2 \end{bmatrix} = -u^2 \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix}\begin{bmatrix} q_1 \\ q_2 \end{bmatrix} - u \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix}\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix}$$

where:

$$H_{11} = 0$$
$$H_{12} = \tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, \Psi(x)\, dx$$
$$H_{21} = 0$$
$$H_{22} = -\tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, \Psi(x)\, dx$$
$$L_{11} = -\tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, \phi(x)\, dx$$
$$L_{12} = -\tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\, y(x)\, \Psi(x)\, dx$$
$$y(x) = .21\, c(x)$$
$$L_{12} = -\tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, \Psi(x)\, dx$$
$$L_{21} = \tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, \phi(x)\, dx$$
$$L_{22} = \tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21\, c(x)^2\, y(x)\, \Psi(x)\, dx$$
$$L_{22} = \tfrac{1}{2}\rho c_{\ell_\alpha} \int_{x_1}^{x_2} (.21)^2\, c(x)^3\, \Psi(x)\, dx$$

Calculation of Loads

$H_{11} = 0$

$H_{12} = \frac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\ \Psi(x)\ dx$

Note: assuming ρ + c_{ℓ_α} are constant across the span, the integration can be performed from $x_1 = 0$ to $x_2 = b/2 = 474$ in.

For SLS, $\rho = .002377$ slug/ft^3

$c(x) = 202.8 - .3215\ x$ (in)

$c_{\ell_\alpha} = .105\ \text{deg}^{-1} = 6.016\ \text{rad}^{-1}$

$H_{12} = \frac{1}{2}(.002377\ \frac{\text{slug}}{\text{ft}^3})(6.016\ \text{1/rad}) \int_0^{474} (202.8 - .3215\,x)\ \Psi(x)\,dx\ (\text{in}^2)$

$H_{12} = 228.2\ \frac{\text{slug in}^2}{\text{ft}^3} = .132\ \text{slug/in}$

$H_{21} = 0$

$H_{22} = -\frac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21\ c(x)^2\ \Psi(x)\ dx$

$= -\frac{1}{2}(.002377\ \frac{\text{slug}}{\text{ft}^3})(6.016\ \text{1/rad}) \int_0^{474} .21(202.8 - .3215\,x)^2\ \Psi(x)\ dx\ (\text{in}^3)\ \frac{\text{ft}^3}{1728\,\text{in}^3}$

$H_{22} = -3.284$ slug

$L_{11} = -\frac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} c(x)\ \phi(x)\ dx$

$= -\frac{1}{2}(.002377\ \frac{\text{slug}}{\text{ft}^3})(6.016\ \text{1/rad}) \int_0^{474} (202.8 - .3215\,x)\ \phi(x)\,dx\ (\text{in}^2)\ \frac{\text{ft}^3}{1728\,\text{in}^3}$

$L_{11} = -.141$ slug/in

$$L_{12} = -\tfrac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21 \, c(x)^2 \, \Psi(x)\, dx$$

$$= -\tfrac{1}{2} (.002377 \tfrac{slug}{ft^3})(6.016 \, {}^1/_{rad}) \int_0^{474} .21 \, (202.8 - .3215x)^2 \, \Psi(x)\, dx \, (in^3) \tfrac{ft^3}{1728 \, in^3}$$

$$L_{12} = -3.284 \text{ slug}$$

$$L_{21} = \tfrac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} .21 \, c(x)^2 \, \phi(x)\, dx$$

$$= \tfrac{1}{2} (.002377 \tfrac{slug}{ft^3})(6.016 \, {}^1/_{rad}) \int_0^{474} .21 \, (202.8 - .3215x)^2 \, \phi(x)\, dx \, (in^3) \tfrac{ft^3}{1728 \, in^3}$$

$$L_{21} = 3.042 \text{ slug}$$

$$L_{22} = -\tfrac{1}{2} \rho c_{\ell_\alpha} \int_{x_1}^{x_2} (.21)^2 \, c(x)^3 \, \Psi(x)\, dx$$

$$= \tfrac{1}{2} (.002377 \tfrac{slug}{ft^3})(6.016 \, {}^1/_{rad}) \int_0^{474} (.21)^2 (202.8 - .3215x)^3 \, \Psi(x)\, dx \, (in^4) \tfrac{ft^3}{1728 \, in^3}$$

$$L_{22} = 89.61 \text{ slug} \cdot \text{in}$$

Thus:

$$\begin{bmatrix} -Q_1 \\ Q_2 \end{bmatrix} = -u^2 (ft^2/s^2) \begin{bmatrix} 0 & .132 \text{ slug/in} \\ 0 & -3.284 \text{ slug} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} +$$

$$- u \, (ft/s) \begin{bmatrix} -.141 \text{ slug/in} & -3.284 \text{ slug} \\ 3.042 \text{ slug} & 89.61 \text{ slug} \cdot \text{in} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix}$$

$$\begin{bmatrix} -Q_1 \\ Q_2 \end{bmatrix} = -u^2 \begin{bmatrix} 0 & 1.584 \text{ lb} \\ 0 & -39.41 \text{ lb} \cdot \text{in} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} - u \begin{bmatrix} -.141 \text{ lb} \cdot \text{s/in} & -3.284 \text{ lb} \cdot \text{s} \\ 3.042 \text{ lb} \cdot \text{s} & 89.61 \text{ lb} \cdot \text{s} \cdot \text{in} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix}$$

Segment Data

Segment	Span (in)	W (lb)	I_x (in^4)	I_y (in^4)	I_z (in^4)	J (in^4)
1	35	422	7270	1220	40,900	48170
2	73	606	6480	1090	36400	42880
3	24	265	3980	618	22400	26380
4	83	659	1750	293	9790	11540
5	63	327	1300	218	7300	8600
6	65	211	747	125	4200	4947
7	65	106	249	42	1400	1649
8	66	66	134	22	752	886

Segment	m ($lb \cdot s^2/in^2$)	I_θ ($lb \cdot s^2$)	EI ($lb \cdot in^2$)	GJ ($lb \cdot in^2$)
1	.0312	.319	1.08×10^{11}	2.70×10^{11}
2	.0215	.284	9.59×10^{10}	2.40×10^{11}
3	.0286	.162	5.90×10^{10}	1.48×10^{11}
4	.0205	.0766	2.59×10^{10}	6.46×10^{10}
5	.0134	.0570	1.92×10^{10}	4.82×10^{10}
6	.00840	.0327	1.11×10^{10}	2.77×10^{10}
7	.00422	.0110	3.69×10^{9}	9.23×10^{9}
8	.00259	.00575	1.98×10^{9}	4.96×10^{9}

$$J = I_x\,(in^4) + I_z\,(in^4) = in^4$$

$$m = \frac{W\,(lb)}{Span\,(in)\;\; 32.2\,(ft/s^2)\;\; 12\,(in/ft)} = \frac{lb \cdot s^2}{in^2}$$

$$I_\theta = \mu\,(lb \cdot s^2/in^4)\;\; I_y\,(in^4) = lb \cdot s^2$$

$$\mu = \frac{.101\,(lb/in^3)}{32.2\,(ft/s^2)\;\; 12\,(in/ft)} = .000261\ \frac{lb \cdot s^2}{in^4}$$; For aluminum

$$EI = E\,(lb/in^2)\;\; I_x\,(in^4) = lb \cdot in^2$$

$$GJ = G\,(lb/in^2)\;\; J\,(in^4) = lb \cdot in^2$$

$$E = 14.8 \times 10^6\ lb/in^2$$

$$G = 5.6 \times 10^6\ lb/in^2$$

Calculation of the Mass matrix:

$$m_{11} = \int_0^L m \phi^2 dx$$

For each segment of the wing, m will be the average value for that segment. Thus:

Segment	$m\ (\frac{lb \cdot sec^2}{in^2})$	$\int_0^L \phi^2 dx\ (in)$	$m\int_0^L \phi^2 dx\ (\frac{lb \cdot sec^2}{in})$
1	.0312	.002	.0000624
2	.0215	.597	.0128
3	.0286	.968	.0277
4	.0205	13.85	.284
5	.0134	33.88	.454
6	.00840	74.34	.624
7	.00422	133.7	.564
8	.00259	216.6	.561

$\Sigma = 2.528$

Thus:

$$m_{11} = 2.528 \ lb \cdot sec^2/in$$

$$m_{22} = \int_0^L I_\theta \psi^2 dx$$

For each segment, I_θ will be the average value for that segment.

Segment	$I_\theta\ (lb \cdot s^2)$	$\int_0^L \psi^2 dx\ (in)$	$I_\theta \int_0^L \psi^2 dx\ (lb \cdot s^2 \cdot in)$
1	.319	.157	.0501
2	.284	4.338	1.23
3	.162	3.608	.584
4	.0766	24.76	1.90
5	.0570	33.47	1.91
6	.0327	47.60	1.56
7	.0110	58.12	.639
8	.00575	64.96	.374

$\Sigma = 8.25$

Thus:

$$m_{22} = 8.25 \ lb \cdot sec^2 \cdot in$$

$$m_{12} = m_{21} = \int_0^L y_\theta \, m \, \phi \, \Psi \, dx$$

For the wing structure, $y_\theta \approx 0$. Thus, $m_{12} = 0$.

Note, the first set of calculations is for the wing only (without stores) When stores are added, the value for y_θ may change, depending on the location of the store. This will be discussed later.

Calculation of the Stiffness matrix.

$$K_{11} = \int_0^L EI \, \phi_{,xx}^2 \, dx$$

For each segment, EI will be an average value for that segment.

Segment	EI (lb·in²)	$\int_0^L \phi_{,xx}^2 \, dx$ (1/in³)	$EI \int_0^L \phi_{,xx}^2 \, dx$ (lb/in)
1	1.08×10^{11}	3.09×10^{-8}	3340
2	9.59×10^{10}	4.52×10^{-8}	4330
3	5.90×10^{10}	1.00×10^{-8}	590
4	2.59×10^{10}	2.11×10^{-8}	546
5	1.92×10^{10}	6.33×10^{-9}	122
6	1.11×10^{10}	2.09×10^{-9}	23.2
7	3.69×10^{9}	3.57×10^{-16}	1.32
8	1.98×10^{9}	1.35×10^{-11}	.03
			$\Sigma =$ 8950

Thus,

$$K_{11} = 8950 \text{ lb/in}$$

$$K_{22} = \int_0^L GJ \, \Psi_{,x}^2 \, dx$$

Segment	GJ (lb·in²)	$\int_0^L \Psi_{,x}^2 dx$ (1/in)	$GJ \int_0^L \Psi_{,x}^2 dx$ (lb·in)
1	2.70×10^{11}	3.83×10^{-4}	1.03×10^{8}
2	2.40×10^{11}	7.54×10^{-4}	1.81×10^{8}
3	1.48×10^{11}	2.24×10^{-4}	3.32×10^{7}
4	6.46×10^{10}	6.40×10^{-4}	4.13×10^{7}
5	4.82×10^{10}	3.24×10^{-4}	1.56×10^{7}
6	2.77×10^{10}	1.91×10^{-4}	5.29×10^{6}
7	9.23×10^{9}	7.56×10^{-5}	6.98×10^{5}
8	4.96×10^{9}	1.15×10^{-5}	5.70×10^{4}

$\Sigma = 3.80 \times 10^{8}$

Thus,

$$K_{22} = 3.80 \times 10^{8} \ \text{lb} \cdot \text{in}$$

Stability Calculations

From Dr. Locke's formulation:

$$\left| [K] + u^2[H] + \lambda u[L] + \lambda^2[M] \right| = 0$$

$$\left| \begin{bmatrix} 8950\ (\text{lb/in}) & 0 \\ 0 & 3.80 \times 10^{8}\ (\text{lb·in}) \end{bmatrix} + \begin{bmatrix} 0 & 1.58\,u^2\ (\text{lb}) \\ 0 & -39.4\,u^2\ (\text{lb·in}) \end{bmatrix} + \begin{bmatrix} -.141\,\lambda u\ (\text{lb/in}) & -3.28\,\lambda u\ (\text{lb}) \\ 3.04\,\lambda u\ (\text{lb}) & 89.6\,\lambda u\ (\text{lb·in}) \end{bmatrix} + \begin{bmatrix} 2.53\,\lambda^2\ (\text{lb/in}) & 0 \\ 0 & 8.25\,\lambda^2\ (\text{lb·in}) \end{bmatrix} \right| = 0$$

$$\left| \begin{bmatrix} 8950 - .141\,\lambda u + 2.53\,\lambda^2 & 1.58\,u^2 - 3.28\,\lambda u \\ 3.04\,\lambda u & 3.80 \times 10^{8} - 39.4\,u^2 + 89.6\,\lambda u + 8.25\,\lambda^2 \end{bmatrix} \right| = 0$$

$$(8950 - .141\,\lambda u + 2.53\lambda^2)(3.80\times10^8 - 39.4\,u^2 + 89.6\lambda u + 8.25\lambda^2)$$
$$- 3.04\lambda u\,(1.58\,u^2 - 3.28\,\lambda u) = 0$$

$$3.40\times10^{12} - 353000\,u^2 + 802000\,\lambda u + 73800\lambda^2 +$$
$$- 5.36\times10^7\lambda u + 5.56\,\lambda u^3 - 12.6\,\lambda^2 u^2 - 1.16\,\lambda^3 u +$$
$$+ 9.61\times10^8\lambda^2 - 99.7\,\lambda^2 u^2 + 227\,\lambda^3 u + 20.9\,\lambda^4$$
$$- 4.80\,\lambda u^3 + 9.97\,\lambda^2 u^2 = 0$$

$$\lambda^4(20.9) + \lambda^3(-1.16\,u + 227\,u) + \lambda^2(73800 - 12.6\,u^2$$
$$+ 9.61\times10^8 - 99.7\,u^2 + 9.97\,u^2) + \lambda(802000u - 5.36\times10^7u$$
$$+ 5.56\,u^3 - 4.80\,u^3) + (3.40\times10^{12} - 353000\,u^3) = 0$$

$$20.9\,\lambda^4 + 226\,u\,\lambda^3 + (9.61\times10^8 - 102\,u^2)\lambda^2 +$$
$$+ (-5.28\times10^7u + .76\,u^3)\lambda + (3.40\times10^{12} - 3.53\times10^5u^2)$$

From Routhe's criterion, A, B, C, D, E ≥ 0

λ^2: $9.61\times10^8 - 102\,u^2 \geq 0$

$9.61\times10^8 \geq 102u^2$

$u \leq 3069$ ft/s $=$ 1817 Kts

λ: $-5.28\times10^7u + .76\,u^3 \geq 0$

$.76\,u^3 \geq 5.28\times10^7u$

$.76\,u^2 \geq 5.28\times10^7$

$u \geq 8335$ ft/s $=$ 4935 Kts

λ^0: $3.40\times10^{12} - 3.53\times10^5u^2 \geq 0$

$3.53\times10^5u^2 \leq 3.40\times10^{12}$

$u \leq 3104$ ft/s $=$ 1840 Kts

To check the mass and stiffness matrices:

$$\omega = \sqrt{\frac{K}{m}}$$

For bending mode:

$$\omega = \sqrt{\frac{K_{11}}{m_{11}}} = \sqrt{\frac{8750 \text{ lb/in}}{2.528 \text{ lb}\cdot\text{s}^2/\text{in}}} = 59.5 \text{ rad/sec}$$

For a uniform beam:

$$\omega = \frac{1.875^2}{L^2}\sqrt{\frac{EI}{m}}$$

Taking average values for EI and m.

$$EI = 5.5 \times 10^{10} \text{ lb}\cdot\text{in}^2$$
$$m = .017 \text{ lb}\cdot\text{s}^2/\text{in}^2$$

$$\omega = \frac{1.875^2}{474^2 (\text{in}^2)}\sqrt{\frac{5.5\times10^{10} (\text{lb}\cdot\text{in}^2)}{.017 \text{ lb}\cdot\text{s}^2/\text{in}^2}} = 28.1 \text{ rad/sec}$$

These two values for ω: (59.5 + 28.1) are close enough to indicate the bending mode was done correctly with the giving data.

For the torsional mode:

$$\omega = \sqrt{\frac{K_{22}}{M_{22}}} = \sqrt{\frac{3.80\times10^8 \text{ lb}\cdot\text{in}}{8.25 \text{ lb}\cdot\text{s}^2\cdot\text{in}}} = 6800 \text{ rad/sec}$$

For a uniform beam

$$\omega = \frac{\pi/2}{L}\sqrt{\frac{CG}{\mu I_p}}$$

where: $C \approx J = 24500 \text{ in}^4$ (average value)
$\mu I_p \approx I_\theta = .16 \text{ lb}\cdot\text{sec}^2$ (average value)

$$G = 5.6\times10^6 \text{ lb/in}^2$$

$$\omega = \frac{\pi/2}{474\ (in)} \sqrt{\frac{24500\ (in^4)\ \ 5.6\times10^6\ (lb/in^2)}{.16\ \ lb\cdot sec^2}}$$

$$\omega = 3100 \ \ rad/sec$$

again, these two values of ω for the torsional mode are close enough to indicate it was done correctly for the given data.

APPENDIX E

The purpose of this appendix is to show the calculations done to determine the life cycle costs of the Good, the Bad, and the Ugly aircraft. The appendix consists of engineering hand calculations and Lotus spreadsheets. The Table of Contents below shows what is included in this appendix.

Table of Contents

The following are input data needed for the Nicolai cost model:

Calculation of AMPR Weight:

	Good	Bad	Ugly
1) Landing Gear	1,174	700	400
2) Engines + Gearbox	4,000	1,800	800
3) Engine Starter	46	16	4
4) Cooling Fluid	0	0	0
5) Fuel System	564	361	137
6) Instrumentation	461	289	178
7) Electrical System	505	376	254
8) Avionics	0	0	0
9) Gun	1200	1,200	1,200
10) A/C, Press.	161	130	111
11) APU	0	0	0
12) TF+O	198	109	55
Subtotal	8,309	4,981	3,139
Empty Weight	20,592	12,358	6,948
AMPR Weight	12,283	7,377	3,809
AMPR / Empty	0.60	0.60	0.55

	Engine SHP	# of Engines	Prop. Dia. (ft)	# of Propellers
Good	6,000	2	8.18	2
Bad	2,500	2	7.10	2
Ugly	2,000	1	7.10	1

Maximum Speed at Best Altitude = 250 Kts for Good, Bad, and Ugly

The following cost data was obtained from References and

From Reference :

Engines SHP	Cost (1989 dollars)
635	\$ 230,000
850	\$ 270,000
1,461	\$ 435,000
2,180	\$ 630,000
2,810	\$ 965,000

A curve was fit between these points to obtain the cost of the engines for the Bad and Ugly airplanes (SHP = 2,500).

From Reference , the cost for turbo-fan engines was obtained. The cost of turbo-prop engine was estimated to be similar to the turbofan cost by Mr. Neal (see Ref.). So,

Engine Thrust	Engine SHP	Cost (1989 dollars)
12,000	4,138	\$1,000,000
25,000	8,621	\$3,000,000
40,000	13,791	\$ 4,500,000
60,000	20,690	\$ 7,000,000

The ratio between engine thrust and engine shp was taken from Reference , Figure , Page .

A curve was fit between these points to obtain the engine cost of the Good airplane (SHP = 6,000).

From the AE 621 Final Report, the following avionic and instrumentation components are to be included and so their cost must be estimated:

Component	Manufacturer / Model
Attack Radar	Westinghouse WX-50
Laser Spot Tracker	Martin-Marrietta AN/AAS-35(V)
Infra-Red Detector	Texas Instruments AN/AAR-42
Mission Computer	Delco Electronics M372
Communications/Radio	Collins AN/ARC-186(V)/VHF-186
	Remote Transceiver
	Half Size Remote Control
	Panel Mounted Transceiver
Inertial Navigator	Kearfott SKN-2416
IFF Transponder	Hazeltine AN/APX-72
Air Data System	Garrett A-10 ADC
Passive ECM (Chaff/Flare)	Tracor AN/ALE-40(V)
Radio Altimeter	Collins AL-55B
CRT (two)	
HUD (canopy projection)	SFENA WGD-2

From the magazine, Business and Commercial Aviation, April 1987 issue, information (manufacturer, weight, price, etc) is available. The following are the groups that the avionics are divided into:

The avionic components will be estimated by choosing the exact component or a component similar to it. The components not available from the above reference will be estimated or determined via conversation with an industry personnel.

The following component cost (because they are military orientated), have to be determined without the use of the above reference:

- attack radar
- laser spot tracker
- infra-red detector
- CRT
- HUD
- Passive ECM (Chaff / Flare)
- Air data system

Mission Computer

A mission computer wasn't found in BCA, April 1987*, so to estimate its cost, the integrated flight control system costs will be used.

The average cost of seven IFCS will be used as the cost of the mission computer for the Good, Bad, and the Ugly. The models and costs are:

Manufacturer	Model	Cost
King / Bendix	KFC 250	$ 59,145
	KFC 325	$ 58,415
	KFC 400	$ 83,480
Honeywell	SPZ-4000	$ 114,251
	SPZ-4500	$ 114,251
	SPZ-500-200A	$ 115,999
	SPZ-8000	$ 140,858
	SPZ-600	$ 243,994

Average cost = mission computer cost = $132,913

Communications / Radio

Remote Tranceiver: The average cost of all the models listed will be used as the cost.

Average Cost = $ 8,215

Collins VHF-186: The price for the Collins VHF-253 will be used instead:

Cost = $ 2,955

Panel Monted Tranciever: The cost of this component will be estimated using the average cost of the listed VHF Panel-monted transceivers in BCA, April 1987.

Average Cost = $ 1,800

* BCA = Business and Commercial Aviation

Inertial navigator

The cost of the inertial navigator will be estimated by averaging the cost of the long-range navigation systems listed in BCA, April 1987.

Average Cost = \$ 46,015

IFF Transponder

The cost of the transponder will be estimated using the average cost of the transponders listed in BCA, April 1987.

Average Cost = \$ 3,780

Radio Altimeter

The radio altimeter specified in the AE 621 report was found in BCA, April 1987:

Cost = \$ 12,815

CRT

The cathode ray tube (CRT) cost was obtained from Bendix / King. A 5"×5" tube costs \$15,125 and the symbol generator for it costs \$ 30,185. With this a 10"×10" tube was estimated to be \$ 25,000 and the symbol generator \$ 38,000 so the cost for one unit in 1989 dollars is:

Cost = \$63,000 / unit

So Total Cost for CRT's = \$126,000

Air Data System

The air data system that Bendix / King sells costs:

Cost = \$ 4,500

HUD

The Heads up display cost was obtained by comparing it to an EFIS (Electronic Flight Instrumentation System) that Bendix/King sells. The price given by Bendix/King was:

Cost = \$118,885 (1989 dollars)

Attack Radar

The attack radar cost will be estimated by assuming that its cost is similar to a weather radar. The average cost of a weather radar, according to BCA, April 1987 is:

Cost = \$33,381

The remaining avionic components:

- laser spot tracker
- infra-red detector
- passive ECM (chaff/flare)

cost have to be estimated using an educated guess, since no other method is available.

The cost of each of these components will assumed (arbitrarily) to be \$25,000 so:

Cost = \$75,000

The following is a summary of the avionics cost, including their cost in 1989 dollars:

Component	1987 Cost	1989 Cost
Mission Computer	\$ 132,913	\$ 142,876
Communications/Radio		
Remote Transceiver	\$ 8,215	\$ 8,831
Collins VHF-186	\$ 2,955	\$ 3,176
Panel Mounted Transceiver	\$ 1,800	\$ 1,935
Inertial Navigator	\$ 46,015	\$ 49,464
IFF Transponder	\$ 3,780	\$ 4,063
Radio Altimeter	\$ 12,816	\$ 13,776
CRT (2)	--	\$ 126,000
Air Data System	--	\$ 4,500
HUD	--	\$ 118,885
Attack Radar	\$ 33,381	\$ 35,883
Laser Spot Tracker	--	\$ 25,000
Infra-red Detector	--	\$ 25,000
Passive ECM	--	\$ 25,000

1989 / 1987 = 121.9 / 113.4 = 1.076

So, the total avionics and instrumentation cost for the Good, Bad, and Ugly airplanes in 1989 dollars is:

Total Cost (1989 dollars) = \$ 584,389

Brian Cox | AE 621 | 4/20/89 | Avionics Cost Revision | 1

The following is a revision of the avionics cost which is done to include the following new sources of information:

1) The Bendix/King Suggested Retail Price List January 1, 1989

and 2) Information received from company representatives at the Society of Automotive Engineering (Aerospace Division) conference in Witicha, KS on April 11, 1989.

The following lists the previous cost estimate and the updated estimate:

Component	Cost Estimate	Updated Estimate
Mission Computer	$ 142,876	$ 142,876
Communications/Radio		
Remote Tranceiver	$ 8,831	$ 8,831
Collins VHF-186	$ 3,176	$ 3,176
Panel-Mounted Trans.	$ 1,935	$ 1,935
Inertial Navigator	$ 49,464	$ 49,464
IFF Transponder	$ 4,063	$ 6,000
Radio Altimeter	$ 13,776	$ 10,000
CRT (2)	$ 126,000	$ 126,000
Air Data System	$ 4,500	$ 60,000
HUD	$ 118,855	$ 350,000
Laser Spot Tracker	$ 25,000	$ 25,000
Infra-Red Detector	$ 25,000	$ 25,000
Passive ECM	$ 25,000	$ 25,000
Attack Radar	$ 35,883	$ 2,000,000 *
Cockpit Instrumentation	$ 0	$ 28,850

* This component cost update is the most significant. An avionic engineer at the conference said the minimum that a modern day multi-function attack radar could be bought for is $3 million. Assuming the radar for these airplanes to be less sophisticated than those used on airplanes such as the F-16, F-18, F-14, etc, $2 million was chosen.

So, the avionic costs are:

Good + Bad : $ 3,148,345

Ugly : $ 948,345 *

*(The ugly does not have a radar.)
(10% was added for components to meet military standards.)

The following is a sample calculation of the Nicolai cost model for the Good airplane:

Input: AMPR Weight = A = 12,283 lbs.
Max. Speed = S = 250 kts
$Q_D = 3$
$Q_P = 500$
$Q = Q_D + Q_P = 503$
Flight Test Rate = 1 / month
Production Rate = 5 / month
Airframe Eng. = \$ 48.3 / hour
Tooling = \$ 34.6 / hour
Manufacturing = \$ 26.9 / hour

89/70 dollar = 3.14
89/79 dollar = 1.68
89/81 dollar = 1.35

1. Engineering Hours

Development

$$D = 0.0396\, A^{0.791} S^{1.526} Q_D^{0.183}$$
$$D = 0.0396\,(12,283)^{0.791}(250)^{1.526}(3)^{0.183}$$
$$D = 379,232 \text{ hours}$$
$$\text{Cost} = (48.3)(379,232)(10^{-6}) = \underline{18.317}$$

Production

$$E = 0.0396\, A^{0.791} S^{1.526} Q^{0.183} - D$$
$$E = 0.0396\,(12,283)^{0.791}(250)^{1.526}(500)^{0.183} - 379,232$$
$$E = 587,938$$
$$\text{Cost} = (48.3)(587,938)(10^{-6}) = \underline{28.397}$$

2. Development Support

$$D = 0.008325\, A^{0.873} S^{1.89} Q_D^{0.183}$$
$$D = 0.008325\,(12,283)^{0.873}(250)^{1.89}(3)^{0.346}$$
$$D = 1.54 \text{ (1970 dollars)}$$
$$1989 \text{ Cost} = \underline{4.836}$$

3. Flight Test Operations

$$F = 0.001244\, A^{1.16} S^{1.371} Q_D^{1.281}$$
$$F = 0.001244\,(12,283)^{1.16}(250)^{1.371}(3)^{1.281}$$
$$F = 0.546 \text{ (1970 dollars)}$$
$$1989 \text{ Cost} = \underline{1.714}$$

4. Tooling

Development

$T_D = 4.0127\, A^{0.764} S^{0.899} Q_D^{0.178} R^{0.066}$

$T_D = 4.0127(12,283)^{0.764}(250)^{0.899}(3)^{0.178}(1)^{0.066}$

$T_D = 929,696$ hours

$Cost = (34.6)(929,696)(10^{-6})$

$Cost = \underline{32.167}$

Production

$T = 4.0127\, A^{0.754} S^{0.899} Q_P^{0.178} R^{0.066} - T_D$

$T = 4.0127(12,283)^{0.754}(250)^{0.899}(500)^{0.178}(5)^{0.066} - 929,696$

$T = 1,640,475$

$Cost = (34.6)(1,640,475)(10^{-6})$

$Cost = \underline{56.76}$

5. Manufacturing Labor

Development

$L_D = 28.984\, A^{0.74} S^{0.543} Q_D^{0.524}$

$L_D = 28.984(12,283)^{0.74}(250)^{0.543}(3)^{0.524}$

$L_D = 1,097,328$ hours

$Cost = (26.9)(1,097,328)(10^{-6})$

$Cost = \underline{29.518}$

Production

$L = 28.984\, A^{0.74} S^{0.543} Q_P^{0.524} - L_D$

$L = 28.984(12283)^{0.74}(250)^{0.543}(500)^{0.524} - 1,097,328$

$L = 14,919,825$

$Cost = (26.9)(14,919,825)(10^{-6})$

$Cost = \underline{401,343}$

6. Quality Control

Development

$Q/C = 0.13 * L_D$

$Q/C = 0.13\,(1,097,328)$

$Q/C = 142,653$ hours

$Q/C = \underline{3.857}$

Production

$Q/C = 0.13 * L$

$Q/C = 0.13\,(14,919,825)$

$Q/C = 1,919,577$

$Q/C = \underline{52.176}$

7. Material and Equipment

$M_D = 25.672\ A^{0.889}\ S^{0.624}\ Q_D^{0.792}$

$M_D = 25.672\ (12,283)^{0.889}\ (250)^{0.624}\ (3)^{0.792}$

$M_D = 1.262$ (1970 dollars)

1989 Cost = $\underline{3.964}$

Production

$M = 25.672\ A^{0.889}\ S^{0.624}\ Q_D^{0.792} - M_D$

$M = 25.672\ (12,283)^{0.889}\ (250)^{0.624}\ (500)^{0.792} - 1,262,366$

$M = 72.592$ (1970 dollars)

1989 Cost = $\underline{227.939}$

8. Engine and Avionics

Engines:

Prop Cost: Cost / Prop = \$350.11 $D_p^2\ (E_p / D_p^2)^{0.12}$

Cost/Prop = \$350.11 $(8.18)^2\ (6,000 / 8.18)^{0.12}$

Cost / Prop = 0.040 (1979 dollars)

1989 Cost /AC = (2)(0.040)(1.68) = $\underline{0.135}$

Engine Cost: Cost /eng = $1.9089 \times 10^6\ (SHP/10^4)^{0.8}$

Cost /eng = $1.9089\ (10^6)\ (6,000\ /10^4)^{0.8}$

Cost /eng = 1.269 (1981 dollars)

1989 Cost /AC = (2)(1.269)(1.35) = $\underline{3.425}$

so Total Cost /AC = 3.425 + 0.135 = $\underline{3.560}$

Development = 10.68
Production = 1,780

Avionics:

Development:

Cost = (584,384 /system)(3 systems)
Cost = $\underline{1.753}$

Production:

Cost = (584,389 /system) (500 systems)
Cost = $\underline{292.195}$

22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

9. Total DT+E Cost

Air Frame Eng.	18.317
Development Support	4.043
Flight Test AC	
Engine + Avionics	12.433
Man. Labor	29.518
Material + Equip	3.969
Tooling	32.167
Q/C	3.837
Flight Test Operations	1.714
Test Facilities	0.000
Subtotal	106.787
Profit	10.679
Total DT+E Cost	117.466

10. Total Production and Unit Cost

Engine and Avionics	2,072.195
Manufacturing Labor	401.343
Material and Equipment	227.939
Sustaining Eng.	28.397
Tooling	56.76
Q/C	52.175
Manuf. Facilities	0.000
Subtotal	2,838.84
Profit	283.884
Total Production Cost	3,122.73

Spreading at DT+E over all 500 aircraft:

1989 Unit Cost = 3,122.73 / 500 + 117.466 / 500

1989 Unit Cost = 6.480

Note: The input values in the current spreadsheet are updated values (engine and avionics) so the results do not match, but the method is identical.

Nicolai Cost Model
The Good

Last Revised:04/30/88

```
          Time                 =    1989.0
          WTO                  =   39608.0 lbs
          AMPR                 =   12283.0 lbs
          Maximum Speed        =     250.0 kts
Flight Test Quantity, QD       =       3.0
Production Quantity, QP        =     500.0
Flight Test Rate               =       1.0 per month
Production Rate                =       8.3 per month
Airframe Engineering           =      48.3 per hour
              Tooling          =      34.6 per hour
        Manufacturing          =      26.9 per hour
     1989/1970 Dollar          =       3.1
     1989/1979 Dollar          =       1.7
     1989/1981 Dollar          =       1.4

       Engine SHP:  6000.0
Prop Diameter(ft):     8.2
Number of Engines:     2.0

         Avionics: 3148345 per system
```

NOTE: All cost figures are expressed in millions of dollars.

1. Engineering Hours

```
         Development:

            D = 0.0396*(A^0.791)*(S^1.526)*(QD^0.183)
            D =    379231.7 hours
          Cost =       18.3

         Production:

            E = 0.0396*(A^0.791)*(S^1.526)*(Q^0.183) - D
            E =    587938.6 hours
          Cost =       28.4
```

2. Development Support

```
                      D = 0.008325*(A^0.873)*(S^1.89)*(QD^0.346)
                      D =        1.5 (1970 dollars)
              1989 Cost =        4.8
```

3. Flight Test Operations

```
            F = 0.001244*(A^1.16)*(S^1.371)*(QD^1.281)
            F =        0.5 (1970 dollars)
    1989 Cost =        1.7
```

4. Tooling

Development:

```
  TD = 4.0127*(A^0.754)*(S^0.899)*(QD^0.178)*(R^0.066)
  TD =   929696.0 hours
Cost =       32.2
```

Production:

```
   T = 4.0127*(A^0.754)*(S^0.899)*(Q^0.178)*(R^0.066)
   T =    1728597 hours
Cost =       59.8
```

5. Manufacturing Labor

Development:

```
  LD = 28.984*(A^0.74)*(S^0.543)*(QD^0.524)
  LD =    1097328 hours
Cost =       29.5
```

Production:

```
   L = 28.984*(A^0.74)*(S^0.543)*(Q^0.524) - LD
   L =   14919825 hours
Cost =      401.3
```

6. Quality Control

Development:

```
 Q/C = 0.13*L
 Q/C =   142652.7 hours
Cost =        3.8
```

Production:

```
 Q/C = 0.13*L
 Q/C =    1939577 hours
Cost =       52.2
```

7. Material and Equipment

Development:

$$MD = 25.672*(A^{0.889})*(S^{0.624})*(QD^{0.792})$$

MD = 1.3 (1970 dollars)

1989 Cost = 4.0

Production:

$$M = 25.672*(A^{0.889})*(S^{0.624})*(Q^{0.792})$$

M = 72.6 (1970 dollars)

1989 Cost = 227.9

8. Engine and Avionics

Engines:

Propeller Cost: $Cost/prop = \$350.11*(Dp^2)*(Ep/Dp^2)^{0.12}$

Cost/prop = 0.04 (1979 dollars)

1989 Cost/aircraft = 0.14 (two propellers per engine)

Engine Cost: Cost data from Pratt & Whitney

Cost/eng = 1.8

1989 Cost/aircraft = 4.9

Total Cost/aircraft = Prop. Cost/AC + Eng. Cost/AC = 5.1

Development: Assume 3 engines per flight test aircraft

1989 Cost = 15.2

Production:

1989 Cost = 2538.9

Avionics:

Development:

Cost = 9.4

Production:

Cost = 1574.2

9. Total DT&E Cost

Airframe Engineering................		18.3
Development Support.................		4.8
Flight Test Aircraft................		94.2
Engines & Avionics......	24.7	
Manufacturing Labor.....	29.5	
Material & Equipment....	4.0	
Tooling.................	32.2	
Quality Control.........	3.8	
Flight Test Operations..............		1.7
	Subtotal	119.0
	Profit (10 percent of Subtotal)	11.9
	Total DT&E Cost	130.9

10. Total Production and Unit Cost

Engine and Avionics.................		4113.1
Manufacturing Labor.................		401.3
Material and Equipment..............		227.9
Sustaining Engineering..............		28.4
Tooling.............................		59.8
Quality Control.....................		52.2
	Subtotal	4882.8
	Profit (10 percent of Subtotal)	488.3
	Total Production Cost	5371.1

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.3 million per a/c.

The 1989 unit cost (at 500.0 units) is:

5371.1 / 500.0 + 0.3 = 11.00

Nicolai Cost Model Last Revised:04/30/88
The Bad

```
         Time                 =    1989.0
         WTO                  =   21833.0 lbs
         AMPR                 =    7377.0 lbs
         Maximum Speed        =     250.0 kts
Flight Test Quantity, QD      =       3.0
Production Quantity, QP       =     500.0
Flight Test Rate              =       1.0 per month
Production Rate               =       8.3 per month
Airframe Engineering          =      48.3 per hour
                 Tooling      =      34.6 per hour
           Manufacturing      =      26.9 per hour
     1989/1970 Dollar         =       3.1
     1989/1979 Dollar         =       1.7
     1989/1981 Dollar         =       1.4

      Engine (SHP):  2500.0
Prop Diameter(ft):      7.1
Number of Engines:      2.0

         Avionics: 3148345 per system
```

NOTE: All cost figures are expressed in millions of dollars.

1. Engineering Hours

Development:

```
   D = 0.0396*(A^0.791)*(S^1.526)*(QD^0.183)
   D =    253371.5 hours
Cost =        12.2
```

Production:

```
   E = 0.0396*(A^0.791)*(S^1.526)*(Q^0.183) - D
   E =    392812.3 hours
Cost =        19.0
```

2. Development Support

```
           D = 0.008325*(A^0.873)*(S^1.89)*(QD^0.346)
           D =          1.0 (1970 dollars)
   1989 Cost =          3.1
```

3. Flight Test Operations

```
                 F = 0.001244*(A^1.16)*(S^1.371)*(QD^1.281)
                 F =          0.3 (1970 dollars)
         1989 Cost =          0.9
```

4. Tooling

Development:

```
  TD = 4.0127*(A^0.754)*(S^0.899)*(QD^0.178)*(R^0.066)
  TD =    629756.3 hours
Cost =        21.8
```

Production:

```
   T = 4.0127*(A^0.754)*(S^0.899)*(Q^0.178)*(R^0.066)
   T =     1170915 hours
Cost =        40.5
```

5. Manufacturing Labor

Development:

```
  LD = 28.984*(A^0.74)*(S^0.543)*(QD^0.524)
  LD =  752458.1 hours
Cost =      20.2
```

Production:

```
   L = 28.984*(A^0.74)*(S^0.543)*(Q^0.524) - LD
   L =  10230797 hours
Cost =     275.2
```

6. Quality Control

Development:

```
   Q/C = 0.13*L
   Q/C =   97819.6 hours
  Cost =       2.6
```

Production:

```
   Q/C = 0.13*L
   Q/C =   1330004 hours
  Cost =      35.8
```

7. Material and Equipment

Development:

```
            MD = 25.672*(A^Ø.889)*(S^Ø.624)*(QD^Ø.792)
            MD =      Ø.9 (197Ø dollars)
    1989 Cost =      2.8
```

Production:

```
             M = 25.672*(A^Ø.889)*(S^Ø.624)*(Q^Ø.792)
             M =     51.1 (197Ø dollars)
    1989 Cost =     16Ø.4
```

8. Engine and Avionics

Engines:

Propeller Cost: Cost/prop = $35Ø.11*(Dp^2)*(Ep/Dp^2)^Ø.12

```
           Cost/prop =    Ø.Ø3 (1979 dollars)
  1989 Cost/aircraft =    Ø.Ø9 (two propellers per engine)
```

Engine Cost: Cost data from Pratt & Whitney

```
            Cost/eng =    Ø.8
  1989 Cost/aircraft =    2.2
```

Total Cost/aircraft = Prop. Cost/AC + Eng. Cost/AC = 2.3

Development: Assume 3 engines per flight test aircraft

1989 Cost = 1.7

Production:

1989 Cost = 1127.4

Avionics:

Development:

Cost = 9.4

Production:

Cost = 1574.2

9. Total DT&E Cost

Airframe Engineering................		12.2
Development Support.................		3.1
Flight Test Aircraft................		58.6
Engines & Avionics......	11.1	
Manufacturing Labor.....	20.2	
Material & Equipment....	2.8	
Tooling.................	21.8	
Quality Control.........	2.6	
Flight Test Operations..............		0.9
	Subtotal	74.9
	Profit (10 percent of Subtotal)	7.5
	Total DT&E Cost	82.4

10. Total Production and Unit Cost

Engine and Avionics.................	2701.5
Manufacturing Labor.................	275.2
Material and Equipment..............	160.4
Sustaining Engineering..............	19.0
Tooling.............................	40.5
Quality Control.....................	35.8
Subtotal	3232.4
Profit (10 percent of Subtotal)	323.2
Total Production Cost	3555.7

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.2 million per a/c.

The 1989 unit cost (at 500.0 units) is:

3555.7 / 500.0 + 0.2 = 7.28

Nicolai Cost Model
The Ugly

Last Revised:04/30/88

Time	=	1989.0
WTO	=	10663.0 lbs
AMPR	=	3089.0 lbs
Maximum Speed	=	250.0 kts
Flight Test Quantity, QD	=	3.0
Production Quantity, QP	=	500.0
Flight Test Rate	=	1.0 per month
Production Rate	=	8.3 per month
Airframe Engineering	=	48.3 per hour
Tooling	=	34.6 per hour
Manufacturing	=	26.9 per hour
1989/1970 Dollar	=	3.1
1989/1979 Dollar	=	1.7
1989/1981 Dollar	=	1.4

Engine (SHP): 2500.0
Prop Diameter(ft): 7.1
Number of Engines: 1.0

Avionics:948345.0 per system

NOTE: All cost figures are expressed in millions of dollars.

1. Engineering Hours

Development:

D = 0.0396*(A^0.791)*(S^1.526)*(QD^0.183)
D = 127265.5 hours
Cost = 6.1

Production:

E = 0.0396*(A^0.791)*(S^1.526)*(Q^0.183) - D
E = 197305.0 hours
Cost = 9.5

2. Development Support

D = 0.008325*(A^0.873)*(S^1.89)*(QD^0.346)
D = 0.5 (1970 dollars)
1989 Cost = 1.4

3. Flight Test Operations

$$F = 0.001244*(A^{1.16})*(S^{1.371})*(QD^{1.281})$$

F = 0.1 (1970 dollars)
1989 Cost = 0.3

4. Tooling

Development:

$$TD = 4.0127*(A^{0.754})*(S^{0.899})*(QD^{0.178})*(R^{0.066})$$

TD = 323842.0 hours
Cost = 11.2

Production:

$$T = 4.0127*(A^{0.754})*(S^{0.899})*(Q^{0.178})*(R^{0.066})$$

T = 602124.3 hours
Cost = 20.8

5. Manufacturing Labor

Development:

$$LD = 28.984*(A^{0.74})*(S^{0.543})*(QD^{0.524})$$

LD = 395108.6 hours
Cost = 10.6

Production:

$$L = 28.984*(A^{0.74})*(S^{0.543})*(Q^{0.524}) - LD$$

L = 5372095 hours
Cost = 144.5

6. Quality Control

Development:

$$Q/C = 0.13*L$$

Q/C = 51364.1 hours
Cost = 1.4

Production:

$$Q/C = 0.13*L$$

Q/C = 698372.3 hours
Cost = 18.8

7. Material and Equipment

Development:

MD = 25.672*(A^0.889)*(S^0.624)*(QD^0.792)
MD = 0.5 (1970 dollars)
1989 Cost = 1.5

Production:

M = 25.672*(A^0.889)*(S^0.624)*(Q^0.792)
M = 28.0 (1970 dollars)
1989 Cost = 88.1

8. Engine and Avionics

Engines:

Propeller Cost: Cost/prop = $350.11*(Dp^2)*(Ep/Dp^2)^0.12

Cost/prop = 0.03 (1979 dollars)
1989 Cost/aircraft = 0.05 (one propeller per engine)

Engine Cost:

Cost/eng = 0.8
1989 Cost/aircraft = 1.1

Total Cost/aircraft = Prop. Cost/AC + Eng. Cost/AC = 1.1

Development: Assume 3 engines per flight test aircraft

1989 Cost = 1.7

Production:

1989 Cost = 563.7

Avionics:

Development:

Cost = 2.8

Production:

Cost = 474.2

9. Total DT&E Cost

Airframe Engineering................		6.1
Development Support.................		1.4
Flight Test Aircraft................		29.3
Engines & Avionics......	4.5	
Manufacturing Labor.....	10.6	
Material & Equipment....	1.5	
Tooling.................	11.2	
Quality Control.........	1.4	
Flight Test Operations..............		0.3
	Subtotal	37.2
	Profit (10 percent of Subtotal)	3.7
	Total DT&E Cost	40.9

10. Total Production and Unit Cost

Engine and Avionics.................		1037.9
Manufacturing Labor.................		144.5
Material and Equipment..............		88.1
Sustaining Engineering..............		9.5
Tooling.............................		20.8
Quality Control.....................		18.8
	Subtotal	1319.6
	Profit (10 percent of Subtotal)	132.0
	Total Production Cost	1451.5

With the RDT&E cost to be spread out over 500.0 aircraft the selling price is increased by 0.1 million per a/c.

The 1989 unit cost (at 500.0 units) is:

1451.5 / 500.0 + 0.1 = 2.98

The following is the method presented in Nicolai for operating and maintenance cost:

Cost is based upon a 10 year period (usually).
The fleet size and number of flying hours per year need to be estimated:
Fleet Size = 100 (for now)
Flying Hours per Year = 300

Determine an average fuel flow per hour, gallon/hour:
From AE 601 Report 1 come the following sfc's for cruise:
Good - sfc = 0.48 lb_f / lb_t-hr
Bad + Ugly - sfc = 0.44 lb_f / lb_t-hr

Fuel Cost of JP-4 ~ \$0.85 / gallon

The above gives the operating fuel costs.

For personnel costs:

For a fighter: $\dfrac{\text{500 Flight Hours}}{\text{Year}} \times 1.1$ (Crew Ratio / AC)

So one a/c for one year requires 550 hours of crew time.

$$\text{Aircrew Cost} = \left(\frac{\text{Flight Hours}}{\text{Year}}\right)\left(\frac{\$\ \text{Wage}}{\text{Hour}}\right) = \text{Yearly Crew Cost}$$

Maintenance Cost:

Annual Flight Hours Per A/C = 300 (based on A-10 use)
Maintenance Man Hours Per FH = 10 (based on A-10, F-15)

$$\text{So}\quad \frac{MMH}{A/C} = \frac{FH}{A/C}\cdot\frac{MMH}{FH} = (300)(10) = 3{,}000\ \frac{MMH}{A/C}\ \text{for one year}$$

With maintenance cost per year, the yearly maintenance cost can be estimated.

So yearly operating cost is

$$(\text{Cost})_{\text{operating}} = \text{Fuel} + \text{Crew} + \text{Maintenance} + \text{Other}$$

The Other cost consists of depot and overhaul, spares, and indirect costs: and will be estimated using Fig. 24.1 of Nicolai, the average of the F-4 and A-7D will be used:

Cost	F-4	A-7D	Average
Indirect	20	20	20
Direct	38	38	38
Spares	12	16	14
Fuel	10	4	7
Depot	13	16	14.5
Misc	7	6	6.5

The Fuel, Crew, and maintenance cost calculated with the previous page should make up for 45% of the total yearly operating cost.

So, (Fuel + Crew + Maint.) + (Other) = Total Yearly Cost

or let Fuel + Crew + Maint = FCM
Other = OT
Total Yearly Cost = TYC

So, $FCM + OT = TYC$

but $FCM = 0.45\ TYC$

So $0.45\ TYC + OT = TYC$

So $OT = 0.55\ TYC$

or $OT = 0.55\left(\frac{FCM}{0.45}\right)$

$OT = 1.222\ FCM$

From Nicos Mills, the BSFC of the engines of all three aircraft can taken as 0.38 lbf/hr/SHP. This is assumed to be static. At cruise the following is assumed:

1) BSFC = 0.42 lbf/hr/SHP
2) Engines operate at 40% max. power

] pending change

For the Good:

$$0.42 \frac{lb_f/hr}{SHP} \times 0.40\,(12{,}000\ SHP) \times \frac{1\ US\ Gallon}{6.55\ lbs} = 307.79\ \frac{gallons}{hr}$$

So $\frac{Cost}{hr} = 307.791 \frac{gallons}{hr} \times \frac{\$0.85}{gallon} = \$\,\frac{261.6}{hr}$

So $((Cost/AC)/Year = (\$261.6/hr)(300\ hr) = \$74{,}480$

So for a fleet of 100: Fuel Cost/Year = \$ 7,848,000

Aircrew Cost = $\left(\frac{550\ hrs}{year}\right)\left(\frac{Aircrew\ \$}{Hour}\right)$

From Factors, Formulas and Structures, from the Air Force LSC Model, the base labor rate in 1977 dollars is \$13.03/hr, so in 1989 dollars:

$$Aircrew\ \$/hr = 2.0\,(\$13.03/hr) = \$26.06\ /hr$$

So

Crew Cost /year /AC = (550 hrs/year)(\$26.06/hr) = \$14,333 / year / AC

So for 100 a/c: Crew Cost/Year = \$1,433,300

Maintenance Cost = $\left(3{,}000 \frac{MMH}{A/C/Year}\right)\left(\frac{\$\ Maintenance}{Hr}\right)$

From the Miscellaneous Factors table the labor rate per productive maintenance man hours is in 1977 dollars \$16.03/hr so in 1989 dollars:

$$Maintenance\ Cost\ /\ Hr = 2(\$16.03/hr) = \$\ 32.06/hr$$

So Maint. Cost/year/A/C = (3,000 MMH/A/C)(\$ 32.06/HR)
= \$96,180. / year / A/C

So for 100 aircraft: Maint. Cost/Year = \$ 9,618,000

So, for one year the operating cost is:

Cost /Year = Fuel + Crew + Maint. + Other

where Other = 1.22 (Fuel + Crew + Maint)
= 1.22 (7,848,000 + 1,433,300 + 9,618,000)
= \$ 23,094,945.6 /Year

So Cost /Year = 7,848,000 + 1,433,300 + 9,618,000 + 23,094,945

Cost /Year \$ 41,994,245

The spreadsheet shown in Chapter 10 uses updated inputs so the numbers may not be equal, but the method is identical to what is shown here.

The effects of commonality were investigated for the development, test and evaulation, and production using the following method:

Step 1 Calculate the unit cost (with no engines or avionics) per lb for 500 units of each airplane.

X/lb = Unit cost per pound of airplane

Step 2 Calculate the unit cost (with no engines or avionics) per lb for 1,500 units of each airplane.

Y/lb = Unit cost per pound of airplane

Step 3 Calculate the unit cost (with engines and avionics) per lb for 500 units of each airplane.

X'/lb = Unit cost per pound of airplane.

Step 4 Calculate the commonality cost as:

Commonality Cost = X'/lb - Common Weight (X/lb - Y/lb)

Where the common weight consists of structural weight which is common between the three aircraft. From Reference , these weights are:

Wing components:	864 lb.
Empennage:	572 lb.
Nose section:	730 lb.
	2,166 lb.

The spreadsheet on the next page shows these calculations for varying production quantities. The results are displayed graphically in the body of the report.

Commonality Cost Calculations

	Good	Bad	Ugly
250			
x/lb	216.1	247	310.7
y/lb	128.5	147.4	186.5
Saving	189742	215734	269017
Commonality Cost	11.61	7.58	2.99
500			
x/lb	154.8	177.3	223.9
y/lb	94.9	109.1	138.5
Saving	129743	147721	184976
Commonality Cost	10.87	7.13	2.80
750			
x/lb	128.5	147.4	186.5
y/lb	80.1	92.2	117.3
Saving	104834	119563	149887
Commonality Cost	10.57	6.93	2.72
1000			
x/lb	113.1	129.8	164.5
y/lb	71.3	82.1	104.6
Saving	90539	103318	129743
Commonality Cost	10.38	6.82	2.67